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Balance Abilities of Workers in Physically Demanding Jobs

With Special Reference to Firefighters of
Different Ages

Doctoral dissertation

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ABSTRACT

The objectives of the present study were to investigate the associations between balance abilities and age, occupation and the use of fire-protective equipment (FPE) in different visual conditions, and the associations of slip and fall risk with balance abilities among workers in physically demanding jobs, especially among workers in fire and rescue work. The reliability and predictive values of balance tests in respect to perceived work ability were also studied.

The professional firefighters aged 30 to 56-years (n=29-135), construction workers (n=52), home care workers (n=66) and nursing workers (n=51) aged 23 to 61 years participated in this study. The data were obtained with balance tests with the use of a force platform, functional balance tests, slipping tests and questionnaires. In one study the balance tests were carried out with and without FPE. The slipping tests with FPE were carried out on a straight 8-m long path that had one area covered by water and detergent or glycerol. Perceived work ability at baseline and after a 3-year follow-up was determined with the use of the work ability index (WAI). In the reliability study, the dynamic balance tests were repeated six times in two testing periods at an interval of 2 months.

The results indicated that the balance abilities of firefighters over 49 years of age were significantly poorer than those of firefighters in the age groups of <40 and 40-49 years. The decline of balance abilities among construction, home care and nursing workers was not as consistent. Postural balance was also more harmfully affected among the older firefighters (43-56 years) than among the younger ones (33-38 years) by the use of FPE without visual input. Self-contained breathing apparatus was the most significant single piece of FPE to impair balance in both groups. Furthermore, fast and controlled performance in the dynamic stability test based on visual feedback was related to smaller slip and fall risk with FPE in both age groups. The older firefighters tended to have longer and more serious slips than the younger ones. In addition, the construction workers were significantly faster and made fewer errors than the firefighters in the functional balance test. Among the firefighters, poor performance on the balance tests significantly predicted a reduced WAI after a follow-up of 3 years. The dynamic stability and functional balance tests showed reasonable reliability, especially when the reliability was estimated from the best of at least three repeated trials.

The present results suggest that balance abilities should be taken into account in follow-ups of the work ability of firefighters, as well as in the organization of work tasks and the development of the characteristics of FPE. It is also essential to provide ample balance training opportunities for firefighters with and without FPE. The balance assessments of the present study can be included when prerequisites of work ability are evaluated and followed-up for firefighters.

National Library of Medicine Classification: WA 440, WA 485, WV 255

Medical Subject Headings: musculoskeletal equilibrium; posture; aging; occupations; rescue work; protective devices; risk factors; occupational exposure; comparative study; cross-sectional studies; follow-up studies, reproducibility of results

To Jarmo, Iina and Elli

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Helsinki, October 2004

Anne Punakallio

LIST OF THE ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications, which are referred to in the text as studies I-V.

- I Punakallio A. Balance abilities of different-aged workers in physically demanding Jobs. *Journal of Occupational Rehabilitation* 2003;13:33-43.
- II Punakallio A, Lusa S, Luukkonen R. Protective equipment affects balance abilities differently in younger and older firefighters. *Aviation, Space, and Environmental Medicine* 2003;74:1151-6.
- III Punakallio A, Hirvonen M, Grönqvist R. Slip and fall risk among firefighters in relation to balance, muscular capacities and age. *Safety Science* (Submitted).
- IV Punakallio A, Lusa S, Luukkonen R. Functional, postural and perceived balance for predicting the work ability of firefighters. *International Archives of Occupational and Environmental Health* 2004;77:482-90 (In press).
- V Punakallio A. Trial-to-trial reproducibility and test-retest stability of two dynamic balance tests among male firefighters. *International Journal of Sports Medicine* 2004;25:163-9.

ABBREVIATIONS

A/D	analogue-to-digital
APA	anticipatory postural adjustment
BOS	base of support
CI	confidence interval
CNS	central nervous system
COG	center of gravity
COM	center of mass
COP	center of pressure
EMG	electromyographic
FPE	fire-protective equipment
ICC	intraclass correlation coefficient
LoA	limits of agreement
LOS	limits of stability
OR	odds ratio
PWA	physical work ability
RCOF	required coefficient of friction
SCBA	self contained breathing apparatus
SD	standard deviation
SEM	standard error of the measurement
WAI	work ability index

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1. INTRODUCTION

The ability to balance is a basic element of daily activity. Due to the high balance demands, sufficient balance abilities are especially important in physically demanding jobs, such as firefighting. Roof work, smoke-diving or the handling of patients and heavy tools are examples of typical tasks carried out in fire and rescue work, in which good individual balance ability can be critical for safe and efficient work performance. Temporary and difficult work conditions and the use of protective equipment further increase the challenges placed on the balance control system. Balance abilities play an important role also in other dynamic physical occupations that include the handling of heavy objects and locomotion in complex environments. High balance demands of a particular type of work may also develop balance abilities, but only a couple of studies have compared the balance abilities of people in different jobs. For instance, construction workers working on high buildings have been shown to sway less than people not engaged in physical work (Gantchev and Dunev 1978).

The workforce is aging globally. For example, the mean age of Finnish fire and rescue, construction, home care and nursing workers is 39, 41, 45 and 41 years, respectively (Tilastokeskus 2003). Most studies of age-related differences in balance have shown that older people are less stable than younger ones. In physically demanding jobs, balance demands are, however, equally high for workers of different ages. Moreover, age-related problems in balance control may increase accident risk (Gauhard et al 2001). The risk increases when visual or proprioceptive inputs are disturbed due to challenging work conditions. Fall victims have been shown to have poor balance control, particularly with their eyes closed (Vouriot et al 2004). Limited data are available about the age and balance abilities of workers in specific physically demanding jobs. Thus far, only one study, that of Pohjonen (2001a), has reported the age-related declines in functional balance among home care workers.

Furthermore, accidents requiring three or more days of sick leave as a result of loss of balance because of slips, trips and falls on level surfaces or falls and jumps from upper to lower levels have been reported to account for considerable proportions of work-related accidents among certain groups of workers in Finland, for example, for 30% and 6% among firefighters, for 22% and 12% among construction workers and for 25% and 3% among workers in health and social services, respectively (Tilastokeskus 1996-2001, Tilastokeskus 2002). The corresponding proportions for Finnish workers in general are clearly lower (20% and 8%) among men and higher (33% and 4%) among women (Tilastokeskus 2002). Slips, trips and falls account for 20% to 40% of disabling occupational injuries in Sweden, the United Kingdom, and the United States (Courtney et al 2001). Moreover, compared with younger workers, workers over

45 years of age have a greater number of slip-, trip- and fall-related accidents (Kemmlert and Lundholm 2001, Tilastokeskus 2002).

Good balance control in relation to a specific task may also promote health and work ability. Pohjonen (2001a) showed that poor balance is a strong predictor of reduced work ability among home care workers and suggested that, in addition to tests of muscular capacities, balance tests should be included in evaluations of the work-related fitness of home care personnel. Several field and laboratory methods are available for evaluating balance abilities, but their relevance and validity to evaluate balance among active working populations with high balance demands have not been established, and, in most cases, their reliability has not been studied according to current recommendations.

This study aimed at investigating associations between balance abilities and age, aspects of work demands and workers' safety in physically demanding jobs, and it especially focused on firefighters. The reliability and predictive value of balance tests in respect to perceived work ability were studied also.

2. REVIEW OF THE LITERATURE

2.1 Concept of balance control and the measurement of balance

Balance is a complex motor skill that describes the dynamics of body posture in preventing falling (Winter 1995). Balance control can be examined from neurophysiological, biomechanical, and functional perspectives depending on the goals of the study. There is, however, no solid consensus regarding the definition of balance control or globally approved "gold standards" for measuring it (Berg 1989, Ekdahl et al. 1989, Pollock et al. 2000). Definitions of balance vary according to the scientific background of the research team using them, and measurements depend on what information is needed and why. The terms "equilibrium", "postural stability" and "postural control" are used as synonyms for balance control (Horak 1987, Karlsson and Frykberg 2000, Shumway-Cook and Woollacott 1995).

From a neurophysiological perspective, balance studies involve the interaction of different levels of balance control mechanisms, whereas, biomechanically, balance can be defined as the ability (balance ability) to maintain or return the body's center of gravity (COG) within the limits of stability (LOS), as determined by the base of support (BOS) (i.e., the area of the feet) (Horak 1987, Nashner 1997). Balance is related to the inertial forces acting on the body and the inertial characteristics of body segments (Winter 1995). Furthermore, the LOS are the boundaries of an area of space in which the body can maintain its position without changing the BOS (Nashner 1997).

The ability to maintain COG within BOS is a typically used definition of "static balance". The term "static" is, however, imperfect, as it ignores the minor automatic adjustments that occur continuously when a body maintains a stable position (Berg 1989). Furthermore, it is the same organ system that is involved in regulating posture in static and dynamic conditions. Mechanisms and strategies for balance control can act differently, however, in static and dynamic tasks. For example, during quiet standing, balance is usually controlled by the ankle strategy, whereas ankle muscle activity alone is insufficient to maintain balance during walking (Winter 1995, Woollacott and Tang 1997). This is one reason for the low correlations between static and dynamic balance tests (Patla et al 1990, Shimada et al 2003, Tsigilis et al 2001). Definitions of static and dynamic balance may, however, be useful when the character and goal of the tool measuring individual balance ability is described.

In static balance tests, the aim is to keep the center of pressure (COP) of the body as immobile as possible within the BOS during standing or sitting (Woollacott and Tang 1997). COP can be calculated from the forces needed when maintaining balance applied to the surface of a force platform (Hirvonen et al 2002). According to Hasan et al (1996a) COP is the position of applied

force vector that is influenced by the shear forces produced by body segment accelerations. Its displacement is a reaction to body dynamics representing all the vertical forces acting on the BOS (Winter 1995). When two feet are in contact with a surface, COP is situated between the feet and depends on the relative weight taken by each foot (Winter 1995). Whereas COP itself is easily quantified and directly measured, body COG is not directly accessible (Hasan et al. 1996a). COG (also referred as center of mass=COM) is the point at which the vector of total body weight passes. It depends only on the displacements of the body segments, but it is not influenced by the dynamics (Winter 1995). Although COG and COP occupy different roles in the balance control system, according to Hasan et al (1996b), their amplitude and frequency measures are highly correlated. This correlation supports the use of COP-based measures in quantifying standing balance. In the present study, static standing balance tests using a force platform are called postural balance tests.

As opposed to the goal of static tests, that of dynamic balance tests is to actively move the COP while standing, walking or different tasks of daily activities are performed. In this study, the term “dynamic stability” refers to a person’s ability to move the COP in a given direction within the LOS in force platform tests. The feet of the testee are not allowed to move. In general, LOS are not fixed boundaries. They change according to the task, the person’s biomechanics, and environmental aspects (Nashner 1997, Shumway-Cook and Woollacott 1995). For example, in walking, the COG is kept within the BOS only during short double-limb support periods (Woollacott and Tang 1997). In all dynamic movements, COG can move outside the LOS for a moment, but BOS has to be changed to bring COG back within BOS; otherwise a fall results. Some researchers have defined static and dynamic balance measurements according to whether the support surface is stable or movable. In dynamic posturography, the support surface can move in a horizontal plane or pitch the person either forward or backward, but the person tries to stand in place (Monsell et al 1997).

Functionally directed balance tests are typically dynamic tests that measure a person’s ability to maintain balance as he or she walks or performs tasks as fast as possible or reaches as far as possible (Hertel et al 2000, Podsiadlo and Richardson 1991, Rinne et al 2001). Ideally, the aim of functionally oriented balance tests is to simulate the tasks and actions of daily activities and work, because balance is one of the baseline requirements necessary for these tasks.

Balance is an integral component of almost all daily actions. Stability and orientation demands of balance changes with each task, and they are higher for activities of greater force, velocity, or magnitude (Berg 1989). Postural orientation is the ability to maintain an appropriate relationship between the body segments and between the body and the environment during a task (Shumway-Cook and Woollacott 1995). In addition to individual and task-

related factors, environmental factors and their interaction affect balance control (Fig. 1) (Shumway-Cook and Woollacott 1995).

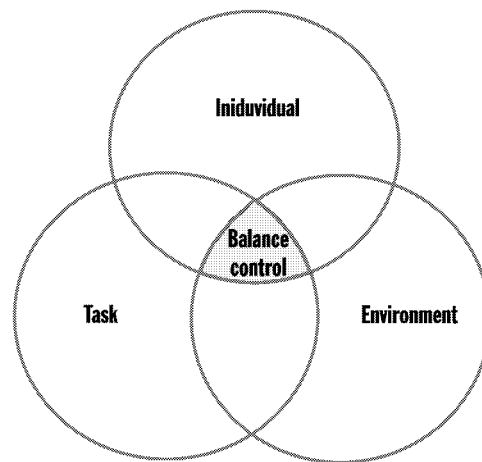


Figure 1. A conceptual model (Shumway-Cook and Woollacott 1995) showing the relationship between the individual, the task demands and the environment with balance control.

2.2 Individual aspects of balance control

2.2.1 Sensory components

The ability to control balance is dependent on sensory inputs from somatosensory, visual and vestibular systems (Table 1). Information concerning the position and movement of body segments with reference to each other and the support surface and the distension of the respective muscles is provided through the somatosensory system, the proprioceptors and the mechanical sensitivity of cutaneous and subcutaneous tissue (Nashner 1997). Proprioceptors are located in muscles, tendons and joints, and they include the following receptor systems: primary endings of muscle spindles (type I), secondary endings of muscle spindles (type II), the Golgi tendon organ and joint receptors (McComas 1996). Muscle stretching activates primary (type I) and secondary (type II) endings of muscle spindles and releases a stretch reflex that monosynaptically facilitates the agonistic muscles and inhibits the activity of the antagonistic muscles (Noback and Demarest 1981).

Muscle spindle type II (secondary endings) mediates the information on the length of the muscles to the central nervous system (CNS) as well. Increasing of

the tension of the muscles also activates Golgi tendon organs (Noback and Demarest 1981). The Golgi tendon reflex effect in respective muscles is opposite of the muscle spindle reflex, namely the activation of Golgi tendon organs causes the facilitation of antagonist muscles, whereas agonistic muscles are inhibited (Prochazka and Wand 1976). These three receptor systems work in harmony by releasing segmental reflexes and mediating information on balance changes to the CNS (Prochazka and Hullinger 1983). Information is also derived from receptors located in the cutaneous and subcutaneous tissue (Johansson and Vallbo 1980) of the sole of the foot. These receptors adapt either slowly or quickly and they can detect changes in pressure, for example, postural sway, and can react to the acceleration and magnitude of skin stretching on the sole of the foot during standing and walking (Johansson and Vallbo 1980, Magnusson et al 1990, Toppila and Pyykkö 2000).

Furthermore, the visual system provides information about the body's position and motion in relation to the environment. Vision has an important role in balance control, but it is not essential because it can also be compensated by other sensory inputs (Brandt et al 1986). According to Brandt et al (1986) visual signals, which start postural corrections, seem to react to motion as a relative image shift on the retina when visual surroundings are stationary. Visual input is needed not only for the continuous evaluation of head sway, but it also seems to trigger required muscle activation in controlling postural perturbations (Brandt et al 1986). In general, the central area of the visual field, when compared with that of the peripheral retina, is more important for balance control, and the foveal region contributes powerfully, especially to lateral postural sway (Paulus et al 1984). When the direction of movement is rapidly changed, it would be impossible to maintain a stable image on the retina without some automatic control mechanism to stabilize the direction of the gaze of the eyes. Therefore, the purpose of the vestibulo-ocular reflex is to stabilize vision by producing eye movements in opposite directions during the turning of the head (Baloh et al 1993, Noback and Demarest 1981). Through this phenomenon the vestibulo-spinal reflex stabilizes the whole body.

Input concerning the position of the head in relation to gravity, as well as to motion through the linear and angular acceleration of the head, is provided by the vestibular system (Noback and Demarest 1981). Vertical and horizontal semicircular canals sense rotational movement of the head in the sagittal and frontal, as well as horizontal, planes, respectively. Canals are the most sensitive to fast movements, for example, those occurring during sudden slips and trips, and they detect movement with a large dynamic range (frequencies 0.5-10 Hz) (Horak and Schubert 1994, Toppila and Pyykkö 2000). Furthermore, the otoliths sense position relative to the earth's gravitation axis and linear and slow (range 0.2-0.5 Hz) acceleration of the head (Toppila and Pyykkö 2000). Saccular otoliths sense vertical linear accelerations of the head (e.g., gravity), for

example, head translations generated during deep knee bends, whereas utricular otoliths sense horizontal linear accelerations like head movements generated during forward walking (Horak and Schubert 1994). The input of otoliths and semicircular canals converges in the vestibular nuclei in the same neuron, which also receives visual and proprioceptive input (Toppila and Pyykkö 2000).

Table 1. Use of sensory inputs for balance control (Adopted from Nashner 1997).

Sensory input	Reference	Conditions favorable to use	Conditions unfavorable to use
Somatosensory	Support surface	Fixed support surface	Irregular or moving support surface
Visual	Surrounding objects	Fixed visible surroundings Irregular or moving support surface	Moving surroundings Darkness
Vestibular	Gravity Inertial space	Irregular or moving support surface Moving surroundings Darkness	Unusual motion environments

Sensory strategies

Sensory strategies, which refer to the relative weight given to a sense by the CNS, vary as a function of such individual aspects as age, task and environment (Table 1). It has been suggested that, under normal conditions, the nervous system weights the importance of somatosensory information for postural control among healthy adults (aged 20-70 years) more heavily than vision does, but, when reliable proprioceptive information is removed, vision becomes more important to the maintenance of balance (Colledge et al 1994). It has also been suggested that there may be a systematic change in the multisensorial process, which controls balance throughout life (Straube et al 1988). Young children (2-8 years) rely more on visual inputs (Straube et al 1988), whereas pressoreceptor and proprioceptor systems are important for balance control among children aged 6 to 16 years (Hytönen et al 1993). Furthermore, the importance of vision in balance control increases again among people over 60 years of age (Hytönen et al 1993, Straube et al 1988), and persons over 85 years of age become especially dependent on vision (Pyykkö et al 1990).

Vision, together with vestibular input, becomes especially important with respect to compensation for continuously applied low-frequency balance disturbances, for example, when the support surface is unstable (Diener et al 1986). Furthermore, vestibular input is critical for balance control when

somatosensory and visual inputs are unavailable, as well as under sensory conflict conditions (Allum et al 1989) (Table 1). According to Colledge et al (1994), the vestibular system alone can only partially compensate, however, for proprioceptive loss. Several studies concern the importance of vestibular inputs in different aspects of balance control; for example, Runge et al (1998) suggested that vestibular information is not critical as regards selecting and triggering hip strategy, although it may be meaningful in controlling hip strategy in some environments. Because the environment is constantly changing, the CNS also has to adapt according to information for multiple sensory modalities in order for balance to be maintained. Therefore, the most appropriate inputs have to be selected according to the requirements of the task and environment (Shumway-Cook and Woollacott 1995).

2.2.2 Integration of motor responses according to sensory input

According to sensory systems and demands of the situation, sensory information is organized, and motor responses are chosen in the CNS to stabilize posture or prevent a harmful change in it (Table 2). The ability to control balance emerges from a reciprocal action of biomechanical, musculoskeletal and sensory systems and the CNS (Nashner 1997). The CNS consists of the spinal cord and the brain. Several parts of the CNS take part in posture control, and there are three motor systems involved in balance control. The first and fastest response to a change in posture is triggered by the *myotatic stretch reflex* (spinal cord), which regulates contractile muscle forces (Noback and Demarest 1981). Reflexes are activated by an external stimulus and are highly stereotyped (Nashner 1997).

The earliest functionally effective responses to balance perturbations are called *automatic postural responses* also referred to as the long-loop reflex or the functional stretch reflex. Their postural latencies (mean 94 ms and 120 ms for medium and long latencies, respectively) are much longer than the spinal stretch reflex latencies (35-40 ms), but they are shorter than voluntary reaction times (≥ 150 ms) (Diener and Dichgans 1986, Nashner 1997). Automatic postural responses, which are mediated in the brain stem and subcortical area, coordinate movements across joints (Nashner 1997). They are stereotyped, but adaptable. Like reflexes, automatic responses are activated by external stimuli. Their responses can be thought of as overlearned, “long-loop” reflexes that rapidly respond by resisting disturbances (Diener and Dichgans 1986). Automatic responses depend on movement strategy, which in turn is dependent on the experience of the person and on surface conditions (Nashner 1997). Automatic reactions are also adaptable to specific balance demands.

Contrary to reflexes and automatic responses, *voluntary postural movements*, mediated by the brainstem and cortical area, can be initiated in response to an

external stimulus, or they can be self-initiated and generate purposeful movements and behavior (Nashner 1997). Postural adjustments associated with voluntary movements are organized on the basis of internal representation (Massion 1994). In order to know when and how to apply restoring forces to keep the COG within the BOS, the CNS must have an accurate picture of where the body is in space and whether it is stationary or in motion (Shumway-Cook and Woollacott 1995). Therefore, internal representations (provided by the postural body scheme) of body geometry, body dynamics (support conditions) and body orientation through sensory inputs are essential for the mapping of sensation to action (Massion 1994) (Table 2).

Table 2. Components of balance control.

Sensory system	CNS	Motor system
Afferent input	Organization of sensory input and choice and triggering of motor responses	Efferent output
Somatosensory system: - proprioceptors: muscle spindle type I and II, Golgi tendon organ, joint receptors - cutaneous and subcutaneous receptors Vision: - retina Vestibular system: - semicircular canals and otholiths in the inner ear	Myotatic stretch reflex Long-loop reflexes Internal representations Learned skills Synergistic action Sensory strategies Adaptive mechanisms Anticipatory mechanisms	Reflexes Automatic movements Voluntary movements Muscles of the upper and lower extremities Trunk and neck muscles Neuromuscular synergies: - ankle strategy - hip strategy - stepping strategy - mixed strategy

2.2.3 Motor components

Balance control requires an ability to produce adequate muscle contractions according to task demands. In simplifying the control demands for the CNS, independent, although related, muscles are combined into muscle synergies by the nervous system (Shumway-Cook and Woollacott 1995). Because the muscles act around the joints when balancing the body, the role of ankle and hip strategies and their related muscle synergies are especially important. The ankle strategy produces shifts in the COG by rotating the body about the ankle joints. It elicits a distal-to-proximal muscle activation of ankle, hip and trunk musculature (Horak and Nashner 1986). The ankle strategy uses compensatory ankle torques that are believed to correct for small postural perturbations on firm

support surfaces (Nashner 1997). Therefore efficient use of the ankle strategy depends on accurate sensations from somatosensory inputs (Horak et al 1990).

The hip strategy controls movement of the COG primarily by flexing and extending the hips, and it uses early proximal hip and trunk muscle activation (Horak and Nashner 1986). Hip strategy occurs when the ankle is unable to exert the appropriate torque necessary to regain balance, for example, when the support surface is smaller than the feet or is compliant or narrow when perturbations are large and fast or when the body COG is near the limits of stability, as it is during walking (Nashner 1997, Horak and Nashner 1986). The third strategy used to achieve balance is the stepping strategy, which is used when the COG is displaced outside the BOS. The stepping strategy uses early activation of hip abductors and ankle co-contraction (Horak and Nashner 1986). The muscle strategies are not as stereotyped as reflexes are. They can also be learned with experience in new environmental contexts (Horak and Nashner 1986). When conditions are intermediate, between favoring the use of the ankle or hip strategy, and when a person must adapt to a new surface condition, for example, to control balance on a flat support as the magnitude of postural perturbations increases, the use of combinations of these strategies (mixed strategies) is common (Runge et al. 1999).

2.2.4 Effects of age and sex on balance control

Decrease of balance abilities with aging

An age-related decline in balance abilities has been shown in several cross-sectional studies of postural sway and functional balance among working-aged populations and the elderly (Colledge et al 1994, Du Pasquier et al 2003, Ekdahl et al 1989, Era and Heikkinen 1985, Gill et al 2001, Matheson et al 1999, Pohjonen 2001a, Røgind et al 2003, Straube et al 1988). Children below 10 years of age and elderly people over 60 years of age have the most pronounced postural sway (Hytönen et al 1993, Pyykkö et al 1988, Sihvonen et al 1998). Some investigations have shown that differences in postural balance abilities in a normal standing position are minor between the ages of 17 and 54 years (Sihvonen et al 1998) or that no correlation exists at all between age and postural sway (Juntunen et al 1987) or that body sway is the most stable among 46-to-60-year-old people (Hytönen et al 1993). When the balance demands of a test are increased (i.e., the BOS is smaller or balance is tested on a compliant surface), when the eyes are closed, or, especially, when the eyes are closed on a compliant surface when two sensory cues are affected, some studies have shown detected balance declines to be greater between younger people and the elderly (>60 years) and between different age groups of the working population (comparisons made for people below and over 40 years of age), and others

report that, among working-aged subjects, declines can only be detected (Colledge et al 1994, Era and Heikkinen 1985, Gill et al 2001, Matheson et al 1999, Straube et al 1988).

It should, however, be remembered that comparisons of the age-related results reported in different studies are complicated due to differences in the methods, the selection of the subjects, the different age ranges of the subjects and the study design. Moreover, most studies on the relationship between balance and age are cross-sectional in design (Colledge et al 1994, Ekdahl et al 1989, Era and Heikkinen 1985, Gill et al 2001, Hytönen et al 1993, Kollegger et al 1992, Matheson et al 1999, Pohjonen 2001a, Røgind et al 2003, Sihvonen et al 1998, Straube et al 1988), and a cross-sectional design is not ideal for obtaining an understanding of the aging phenomenon. In longitudinal studies findings of age-related changes have, however, confirmed the results of cross-sectional studies, and balance deterioration in people over 75 years of age has been shown to be even more pronounced (Baloh et al 1998, Du Pasquier et al 2003, Era et al 2002). Despite the considerable amount of research available on age-related differences in balance, very little is known about age-related differences in the balance of workers in specific physical jobs.

Age-related changes in senses, reflexes and automatic muscle responses

Changes in balance control mechanisms due aging take place at different levels of the balance control system (Woollacott et al 1986). There is, however, no solid consensus concerning mechanisms contributing to these changes (Colledge et al 1994, Laughton et al 2003). In addition, most of the studies of mechanisms contributing to age-related balance changes have dealt with elderly subjects (mean age about 70 years) and young controls of about 20 years of age. Age-related deficits in peripheral sensory systems are important factors, as an elderly person's balance is more altered than that of younger adults when visual and proprioceptive or both inputs are eliminated or reduced (Matheson et al 1999, Shumway-Cook and Woollacott 2000, Straube et al 1988, Woollacott et al 1986).

For example, the following changes take place in the senses as a result of aging: older people have higher proprioceptive thresholds (Stelmach and Sirica 1987) and anatomical changes take place in the semicircular canals, the saccule and the utricle of the inner ear (Johnson and Hawkins 1972). Furthermore, visual acuity declines with age, depth perception and contrast sensitivity are poorer among the elderly, and older people progressively lose their peripheral vision (Cohn and Lasley 1985, Gittings and Fozard 1986). Age-related changes in the aforementioned sensory inputs could decrease the redundancy of sensory information that is normally available and can, therefore, make a shift in the relative weighting of inputs less effective, depending on the environmental

demands (Woollacott et al 1986). Colledge et al (1994) studied 20-to-70-year-old healthy adults and suggested that the relative contributions of sensory inputs to balance do not, however, alter with advancing age.

Age-related changes in the long latency automatic postural response systems characterize reduced muscle coordination (e.g., temporal breakdown of distal and proximal muscle activation) and increase the absolute latency of distal muscles within a muscle response synergy (Woollacott et al 1986). The variability of the relative constancy of the contraction amplitude of distal and proximal synergies also increases with aging (Woollacott et al 1986). The latency of the monosynaptic stretch reflex, which is the lowest level of the balance control hierarchy, increases in the achilles tendon with age (Carel et al 1979), whereas in the patellar tendon no significant differences have been found between 20- and 60-year-old men (Clarkson 1978). Furthermore, Woollacott et al (1986) found impaired integration of sensory inputs among older subjects.

Changes in higher integrative mechanisms

In their study Stelmach et al (1989) found that elderly subjects adapt more poorly to repeated small-slow balance perturbations, which activate integrative mechanisms through sensory inputs, than young controls did, although the two groups responded similarly to large-fast rotations (elicit reflexive postural responses). The continuous control of balance is, however, highly dependent upon the quality of the proprioceptive information, and its integration with visual and vestibular information, and it is not based upon reflex mechanisms (Woollacott et al 1986, Stelmach et al 1989). Therefore, older people are at some disadvantage when balance is under the control of slower, higher level sensory integrative mechanisms (Stelmach et al 1989).

More recent studies have also provided additional evidence that higher integrative levels dominate in the decline of postural control (Colledge et al 1994, Rankin et al 2000, Shumway-Cook and Woollacott 2000). For example, an enriched sensory context is not necessarily related to more stable behavior among elderly people because the reintegration of ankle proprioceptive input causes faster postural sway both with the eyes open and with them closed (Teasdale and Simoneau 2001). Therefore, in addition to decreased peripheral acuity among older people, their sensory reweighting process is limited by the capacity of the central integrative mechanisms that reorganize the hierarchy among the sensory inputs (Teasdale and Simoneau 2001). Colledge et al (1994) also suggested that the increase in body sway demonstrated with normal aging is more likely to be due to the slowing of central integrative processes than to altered peripheral sensibility.

Furthermore, people have shown poorer balance when they perform a simultaneous cognitive task than when they do a balance task only (Shumway-

Cook et al 1997, Shumway-Cook and Woollacott 2000). Balance during a simultaneous cognitive task is more affected among the elderly than among younger persons when the accuracy of visual and somatosensory inputs is reduced (Shumway-Cook et al 1997, Shumway-Cook and Woollacott 2000). A recent experiment of Rankin et al (2000) demonstrated that, especially among older people, muscle activity declines significantly in the gastrocnemius and tibialis anterior muscles if balance is measured when a math task is performed concurrently. These findings suggest that the elderly have a lower attentional processing capacity for balance control during a dual-task paradigm.

Age-related changes in neuromuscular synergies and muscle function

With respect to output, the slowing of peripheral nerve conduction velocity and the decrease in the number of motor units may also be related to balance changes among the elderly (Leonard et al 1997). Furthermore, elderly people have been found to have mixed hip-ankle activation when the BOS is narrowed during standing, whereas young subjects adapt to increased postural demands by using the ankle strategy only (Amiridis et al 2003). Okada et al (2001) also showed that older people rely more on hip movements to control balance while young controls rely on ankle movements. The greater hip muscle activation in the elderly may be caused by insufficient torque production of the ankle muscles, which is needed to counteract the great moment of inertia in the anteroposterior direction (Amiridis et al 2003, Kuo and Zajac 1993). According to Kuo and Zajac (1993) the hip strategy is the most effective in controlling the COM with minimal muscle activation.

The greater hip muscle activation in the elderly may also be caused by greater loss of motor units in the distal than the proximal muscles or an insufficient proprioceptive contribution (Amiridis et al 2003, Stelmach and Sirica 1987). The elderly have also been found to have a greater amount of muscle activity during postural sway in a quiet stance than younger persons do (Laughton et al. 2003). The authors concluded that it is, however, unclear if high muscle activity of the legs precedes greater postural instability or if increased muscle activity is a compensatory response to increases in postural sway (Laughton et al 2003).

Effects of sex on balance control

In some studies, men have been reported to sway more than women (Ekdahl et al 1989, Era et al 1996, Juntunen et al 1987, Kollegger et al 1992, Maki et al 1990, Matheson et al 1999). Other studies have reported contradictory findings (Panzer et al 1995) or no difference between the sexes (Colledge et al 1994, Hageman et al 1995, Røgind et al 2003). Moreover, no results of functional

balance tests (walking time, standing on one leg) have depended on sex (Ekdhahl et al 1989). It has been shown, however, that standardizing the balance results by the length of the base of support or body weight removes the difference between the sexes (Era et al 1996, Maki et al 1990).

2.2.5 Effects of vision on balance control

It is well known that, in the eyes-closed condition, the velocity and amplitude of postural sway is higher than in the eyes-open condition (Colledge et al 1994, Matheson et al 1999, Stelmach et al 1989). For example, postural sway was shown to increase two- to threefold with the eyes closed in all age groups of men and women aged 15-25, 45-55 and 65-75 years and also among men aged 31-35, 51-55 and 71-75 years (Era and Heikkinen 1985, Gill et al 2001). The increase in sway in a normal standing position after the eyes are closed is clearer in the anteroposterior direction (Era and Heikkinen 1985). Paulus et al (1984) showed that especially anteroposterior sway increased gradually as visual acuity decreased. Slower speed and smaller amplitude of COP movement in postural balance tests are associated with better visual acuity among elderly men and women (Era et al 1996).

2.3 Work task demands and balance control

2.3.1 Characteristics of task-related balance control demands in physical jobs

Physically demanding work includes several complicated tasks in which the perturbation of balance is expected. The expected threat to balance also causes anticipatory postural adjustment (APA) (Belen'kii et al 1967, Cham et al 2002, Commissaris and Toussaint 1997a, Cordo and Nashner 1982, Marigold and Patla 2002). APA activates the postural muscles and actively initiates movements, which in advance counteract the possible disturbances of balance associated with a voluntary task and locomotion. For example, pushing a rigid handle while standing is associated with tibialis anterior activation, which precedes the onset of the handle force signal (Cordo and Nashner 1982). This APA compensates for the body displacement induced by the voluntarily performed handle movement.

In physical jobs APA are needed in respect to work safety, but it is as important in respect to the fluency and efficiency of work (Belen'kii et al. 1967). The anticipatory activation of muscles before a voluntary task is associated with the need to maintain balance at the minimum expenditure of energy (Belen'kii et al 1967). According to Zettel et al (2002) the CNS is able to use exteroceptive visual input to alter balance control parameters in an

anticipatory manner, even when the characteristics of the forthcoming perturbation cannot be predicted in advance. When the conditions in which a task is performed change, the preparation for the movement also changes in a way that ensures balance in the new situation (Belen'kii et al 1967). Balance adjustments and the sequence in which postural muscles have been activated are also task-specific (Belen'kii et al. 1967, Commissaris and Toussaint 1997a, Toussaint et al 1997).

The work tasks that challenge balance control the most among firefighters are associated with work with ladders, on roofs and when smoke-diving (Gledhill and Jamnik 1992a, Lusa et al 1994). Tasks demanding good balance abilities are involved in work on scaffoldings and roofs among construction workers (Hsiao and Simeonov 2001). Furthermore, in nursing and home care work, as well as in construction, firefighting and rescue work, manual lifting of clients or construction material and the handling of heavy tools are essential parts of the work. For example, the clients of municipal home care workers in Finland are frail and elderly, and they need help with daily living activities several times a day (Pohjonen 2001b).

Lifting a load in front of the body creates a risk of falling forward because adding the extra mass causes the COP to shift forward in relation to the BOS (Commissaris and Toussaint 1997b). Pan et al (2003) examined postural stability in association with four lifting methods commonly used by drywall installers and carpenters. They found that vertical lifting of drywall sheet placed greater demands on their subjects' balance control (i.e., higher COM accelerations and greater postural sway) than horizontal lifting of drywall. To minimize the effects of balance-threatening events during lifting, preparatory actions immediately before a load, placed in front of the toes in lifting is grasped, are characterized by a lower forward rotational velocity, a clear increase in the backward-directed horizontal momentum of the body COP and a backward-directed horizontal force vector, as well as forward displacement of the COP (Commissaris and Toussaint 1997b, Toussaint et al 1997). During lifting the electromyographic (EMG) activity of ankle plantar flexors increases considerably before contact with the load (Commissaris and Toussaint 1997b).

In one study, if the weight of the lifted load was reduced unexpectedly (16 kg to 6 kg), balance was disturbed in most of the trials (Commissaris and Toussaint 1997a). In general, the APA scales the amplitude of adjustment according to the size or amplitude of the expected perturbation (Shumway-Cook and Woollacott 1995). When a worker overestimates the weight of a load to be lifted, an unnecessarily high linear and angular momentum of the body occurs. This momentum can lead to disturbed balance and possibly to a fall (Commissaris and Toussaint 1997a, Toussaint et al. 1997a). Moreover, Aruin et al (1998) suggested that higher instability during task performance can also be expected to lead to smaller APA because the CNS makes a logical and deliberate choice to

help decrease the probability that the APA itself will produce postural instability.

2.3.2 Effects of protective equipment on balance control

The use of both bulky tools and protective equipment increases the demand for highly developed and flexible balance skills (Hsiao and Simeonov 2001). A worker's balance control can be affected by specific items of protective equipment, such as footwear, clothing, eyeglasses and respirators (Hsiao and Simeonov 2001). For example, shoes act as a sensory interface between the foot and the BOS. The properties of the shoes affect the functional limit and the slip resistance of the BOS and the sensitivity of the foot according to extent, friction, firmness and incline of the surface (Hsiao and Simeonov 2001). The soles of a person's shoes considerably affect the frictional properties of the shoes (Grönqvist 1995). It has been shown that shoes with thin hard soles provided good walking stability, whereas shoes with thick, soft soles reduced foot position awareness and destabilized the walking stability of men of different ages (Robbins et al 1997, Waked et al 1997).

Protective eyeglasses, masks and other face or head protectors can form a sensory interface to the visual system. They restrict the peripheral visual field, and therefore protective eyewear may have harmful effects on balance (Samo et al 2003). Respirators and protective clothing can also influence balance control. Firefighters have to carry out tasks with fire-protective equipment (FPE), consisting of specialized clothing and a self-contained breathing apparatus (SCBA), at least a few times each year (Lusa et al 1994). Furthermore, firefighters need to be able to work safely with FPE, while still maintaining sufficient physical capacity for the most demanding tasks. However, the use of FPE also has negative effects on performance. For example, for submaximal work in a thermoneutral environment, the use of standard European FPE (Committee of Standardization 1995) with SCBA weighing 15 kg increases cardiorespiratory strain by 20% (Louhevaara et al. 1984), and it also significantly increases thermal strain (Ilmarinen and Mäkinen 1992). The strain caused by SCBA is partly due to the weight of the equipment (Louhevaara et al 1984), which, together with increased heat stress, may also affect postural stability (Kincl et al 2002).

Kincl et al (2002) showed that standard United States FPE impaired postural stability in terms of sway length and sway area, especially after physical loading (sustained squatting). These findings indicate that wearing a heavy respirator during demanding physical work may disturb balance (Kincl et al 2002, Seliga et al 1991). Previous studies on postural sway and FPE have, however, used subjects in a narrow age range (24-34 years) (Seliga et al 1991) or failed to examine age-related effects (Kincl et al 2002). Although the effects of European

FPE (Committee of Standardization 1995) on the cardiorespiratory system have been well quantified (Ilmarinen and Mäkinen 1992, Louhevaara et al 1984), no data are available on balance control.

2.3.3 Differences in the balance abilities of workers in various occupations

In general, only a few studies have dealt with balance control in different occupations. According to Kohen-Ratz et al (1994) fighter pilots demonstrate superior and more-mature postural control than candidates for flight training, whereas helicopter pilots show intermediate balance values. Although helicopter pilots are also highly selected, they represent a group not chosen as fighter pilots (Kohen-Ratz et al 1994). Diard et al (1997) also reported that pilots on active duty had significantly better performance in dynamic posturography than former fighter pilots, firefighters and a control group of the general working population. Nurses showed better performance in a Flamingo balance test than a reference group of adults with various occupations, whereas public servants scored better than nurses (Zinzen et al 1996) and construction workers had better stability than workers not engaged in physically demanding work (Gantchev and Dunev 1978). Reported differences in balance abilities could be caused either by an innate ability or by training and learning (Kohen-Ratz et al 1994).

Furthermore, dancers are found to be able to minimize COG displacement towards the supporting side when raising one leg laterally to an angle of 45 degrees in response to a light (Mouchnino et al 1992). Compared with naive subjects, dancers reach the new COG position faster and require only a short adjustment period. Especially under sensory challenged conditions professional dancers were better than controls in maintaining their balance in a one-legged stance (Crotts et al 1996). These differences may be due to the better internal representation of the biomechanical limits of the stability of dancers (Mouchnino et al 1992). Era and Heikkinen (1985) reported that differences in postural sway are minor between manual and office workers.

2.4 Environmental factors involved in balance control

2.4.1 Effects of the visual and physical environmental factors on balance control

Workers maintain their balance by means of visual and physical interaction with the work environment, such as their interaction with the surface on which they stand (Hsiao and Simeonov 2001). The work environment can also consist of such aspects as exposure to noise, lead and organic solvents, which have detrimental effects on balance (Juntunen et al 1987, Ratzon et al 2000, Kuo et al

1996). For example, men with long-term exposure to impulse noise in the military service had poorer postural balance than controls (Juntunen et al. 1987).

Visual input from the work environment is used in a feedback mode (reactive) to control balance during walking and standing or in a feed-forward (anticipatory) mode to help guide locomotion on different surfaces and avoid obstacles (Patla 1997). Several factors in a visual environment, such as the distance between the eyes and the closest object in the visual field and between the eyes and the visual target, as well as the visual target size and contrast, affect balance control (Paulus et al 1984). Furthermore, elevation (3 m and 9 m) increases postural sway, and this effect is correlated with the absence of close visual references and fear of falling (Hsiao and Simeonov 2001, Simeonov and Hsiao 2001). For example, during construction work at an elevation, when workers direct their eyes to a distant target (i.e., to the ground, a tree or a house) their visual field may not include close visual references (Simeonov and Hsiao 2001). The recent report of Simeonov et al (2003) also showed that the destabilizing effect at heights without close visual references is similar to that of the eyes being closed at ground level. Furthermore, height vertigo is associated with postural instability in conditions in which visual references are farther away than 2.5 m (Brandt et al 1980, Paulus et al 1984). The effect of height with the absence of close visual contrasts was found to be substantially more pronounced on uneven surfaces than on normal surfaces (Simeonov and Hsiao 2001).

Moving visual scenes can affect postural stability harmfully; for example, while on a roof, a worker may look at a tree moving in the wind or at swinging objects such as materials moved by a crane (Hsiao and Simeonov 2001). Fall incidents can also occur as a result of a worker miscalculating distance and depth (Clark et al 1996, Hsiao and Simeonov 2001). The detection of obstacles and changes in the properties of surfaces are critical for the anticipatory control of balance (Hsiao and Simeonov 2001). Successful anticipatory detection of potential hazards in the visual environment depends on how distinguishable they are from their surroundings, on subject visual attention and on the prior experience and knowledge of the worker (Hsiao and Simeonov 2001, Patla 1997). Poor lighting detrimentally influences postural balance, especially in more demanding reach and bending tasks, compared with the stationary postural task (Bhattacharya et al 2003). Firefighters, for instance, work frequently in heavily smoky or totally dark environments where visual input is poor. In these conditions balance is maintained through proprioceptive and vestibular systems (Nashner 1997).

In firefighting and rescue work, as in other physical jobs, the surfaces are frequently compliant, narrow, inclined or slippery, of all which challenge the balance control system by involving different strategies to maintain postural stability (Cham and Redfern 2002, Leroux et al 2002, Marigold and Patla 2002).

Increase in the slope and height of a surface have been shown to increase postural sway synergistically (Simeonov et al 2003, Bhattacharya et al 2003). Furthermore, during locomotion, a more cautious walking strategy seems to be adopted when a potential risk of slipping exists (Cham and Redfern 2002, Marigold and Patla 2002); the foot is placed more flatly, and therefore the foot contact area increases, and the COM is kept closer to the contralateral limb, which is in contact with the stable surface (Marigold and Patla 2002). The stance duration and loading speed of the supporting foot are smaller, and the stride length is shorter; Thus the strength requirements of walking are decreased. According to Cham and Redfern (2002), anticipation of slipping trials produced peak values for the required coefficient of friction (RCOF) (shear forces divided by normal forces) that were 16-33% lower than the corresponding values in the baseline trials. The RCOF is believed to best reflect aspects of the ground reaction forces in the contribution of the shoe-floor interface to slip and fall potential.

Working on inclined surfaces also produces an increased risk for slipping due large shear forces at the shoe-floor interface (Hsiao and Simeonov 2001). The RCOF increases linearly with increasing inclination (Redfern et al 2001). An inclined surface affects balance control by altering sensory input from the foot and ankle as a result of a reduced effective BOS and modified position (Hsiao and Simeonov 2001, Simeonov et al 2003). Furthermore, anticipation during walking down an inclined surface results in a reduced stride length and stance duration (Cham and Redfern 2002). According to Leroux et al (2002), the main strategy in standing on a slope is to maintain the COG within the BOS by orienting the trunk and pelvis in relation to the earth's vertical across slopes. During standing on a slope, to provide postural stability, the ankle joints become plantar- or dorsiflexed, and a stretching or contraction of the muscles occurs that controls the movement of the ankle joints (Simeonov et al 2003). The increase in muscle activity and stiffness at the ankle joints probably cause an increase in sway velocity (Simeonov et al 2003).

2.4.2 Balance control during slipping

The activity of the bilateral leg and thigh muscles, as well as the coordination between the lower extremities, has been shown to be important with respect to reactive balance control in slips occurring at heel strike (Tang et al 1998). During a slipping event, ankle moment has been shown to decrease with the severity of the slip, and knee flexor and hip extensor moments are primarily responsible for any corrective balance reactions (Cham and Redfern 2001). Key factors that distinguish between subjects who fall due to a slip and those who maintain their balance are an increased slip distance of the foot (Brady et al 2000) and a shorter double support phase on a slippery surface (You et al 2001).

According to different studies, the critical slip distance between an avoidable and unavoidable fall is 5-22 cm (Brady et al 2000, Grönqvist et al 1999, Strandberg and Lanshammar 1981).

Reactive recovery responses to unexpected slipping (first trial) consist of a rapid onset of flexor synergy, range 150-200 ms, and this synergy suggests that polysynaptic reflexes contribute to the regain in balance and that proprioceptive cues are responsible for triggering the response (Marigold and Patla 2002). Furthermore, a large arm elevation strategy, which helps stabilize COM by shifting it more anteriorly, and a modified swing limb trajectory are used as balance recovering strategies (Marigold and Patla 2002). In addition, grasping, arm swinging and compensatory stepping are efficient means of restoring balance (Redfern et al 2001). The reweighting of the different cues controlling balance has been found to be less efficient among fall victims than among controls (Vouriot et al 2004).

When a subject is exposed repeatedly to slip perturbation, the knowledge of the slip results in a shift in the medial-lateral COM closer to the support limb at foot contact, as well as in a flatter foot landing. Muscle response magnitude and braking impulse are also diminished (Marigold and Patla 2002). The reactive strategies to help maintain balance during slipping are influenced by knowledge of the surface characteristics and prior experience, and therefore the recovery strategies are modifiable (Cham and Redfern 2001, Marigold and Patla 2000).

2.5 Balance assessment of workers in physical jobs

2.5.1 Work-related validity

Although the importance of balance abilities in physically demanding jobs has already been recognized (Hsiao and Simeonov 2001, Lusa 1994), there is limited knowledge of the validity of the balance tests in use. Valid work-related balance tests are, however, needed for purposes of screening in occupational health care and for rehabilitation so that the effects of balance training can be evaluated. When the work-related validity of a physical test is evaluated, it is necessary to examine how a test result is associated with and predicts performance in an actual work situation (*criterion-related validity*). The problem in practice is the lack of quantification for gold standards (King et al. 1998). In general, the definition of work- or performance-related fitness is complex, and the main problem is the lack of a conception of the optimal level of balance tests or other fitness tests, in respect to work (Pohjonen 2001b).

Test drills that simulate physically demanding work tasks have been developed and validated for evaluating firefighters' physical work capacity, mainly in terms of aerobic capacity (Louhevaara et al 1994, Williford et al 1999). Although some of the drills also include tasks that demand, among other

capacities, balance and agility, the outcome variable is either performance time or heart rate without any measurement of balance abilities specifically (Gledhill and Jamnik 1992b, Louhevaara et al 1994, Misner et al 1989). Performance-related balance tests that simulate important daily activities for the elderly, such as walking, rising from a chair and turning, have also been developed and validated (e.g., Berg 1992, Podsiadlo and Richardson 1991). Furthermore, widely used posturography tests of standing balance have been shown to differentiate between workers with various balance abilities (Gantchev and Dunev 1978, Kohen-Ratz et al 1994). "Standing still" tests on a force platform have, however, been criticized for their inability to predict changes in functional balance and gait (O'Neill et al 1998).

Another method of validating a work-related balance test is to measure its ability to predict future work capacity or disability (*predictive validity*). Predictive validity studies of balance tests have mainly focused on the association between balance and low-back pain among working populations (Takala and Viikari-Juntura 2000), between balance and health-related fitness (Suni 2000) and between balance and risk of falling among the elderly (Brauer et al. 2000, Lord and Clark 1996). Other than those of a study on functional balance among home care workers (Pohjonen 2001a), no data are available on the predictive values of balance tests in respect to work ability. The study of Pohjonen (2001a) showed that the perceived work ability of home care workers with poor performance in the functional balance test was 6.5 times more likely to decrease during a 5-year follow-up than that of workers with a good result.

Furthermore, *the content validity* of a test is based on theoretical arguments in relation to a job analysis of the degree to which the test measures the physical demands of the job (King et al 1998). Content validity should, however, not be used as the only basis for determining the validity of a test. With respect to aspects of content validity, most tasks in physically demanding jobs require balance control during movement in difficult conditions. Therefore the work-related balance tests used should also be dynamic or otherwise related to task and environmental demands for balance, such as the demands of different surfaces, the BOS and visual conditions.

2.5.2 Reliability

In addition to validity, reliability is an essential characteristic of a measure, but it is not so complicated to establish (King et al 1998). In fact, to be valid, a test must also be reliable, because a test that measures what it is supposed to measure must consistently provide the same results day after day (Baumgartner 1989). It is necessary to establish reliability between test and retests (*test-retest reliability*), as well as between testers (*interrater reliability*). According to Atkinson and Nevill (1998) some amount of error is always present in physical

tests. Systematic bias is a general trend for test results to differ in a particular direction between several tests. Usually systematic bias is associated with the effects of learning, training or fatigue. Random error is the other type of error related to physical test results. It is usually larger than systematic bias. Inherent biological or mechanical variation or inconsistencies in the test protocol can be the reasons for large random error (Atkinson and Nevill 1998).

Suitable and multiplex statistical analyses of reliability have also been called for (Atkinson and Nevill 1998). Different kinds of correlation coefficients are useful for measuring the relative reliability of showing the degree to which subjects maintain their position within a sample (Baumgartner 1989), but, according to Atkinson and Nevill (1998) and Lamb (1998), they should not be employed on their own as an assessment of reliability. Therefore, it has been recommended that both an appropriate correlation coefficient and a method for absolute reliability (i.e., coefficient of variation, limits of agreement (LoA) or standard error of measurement (SEM) be used (Atkinson and Nevill 1998, Baumgartner 1989). Absolute reliability focuses on the amount of error to expect in a person's score, and it makes it possible to consider the practical significance of the reliability result as well (Atkinson and Nevill 1998, Baumgartner 1989). Since some amount of error is always present in physical test results, absolute reliability can show the amount of error that could be acceptable in the practical use of a test (Atkinson and Nevill 1998). Furthermore, in order to evaluate the effects of learning and training, more than two test sessions are recommended (Atkinson and Nevill 1998). The process of the reliability evaluation should also show whether or not a test needs more familiarization trials or more time between repeated trials. The following sections present examples of reliability studies of methods assessing postural balance, dynamic stability and functional balance abilities mainly among working-aged people.

Postural balance

Using the Good Balance measurement system (Metitur 2001), Mustalampi et al (2003) showed intraclass correlation coefficient (ICC) values of 0.56-0.90 for postural balance tests (anteroposterior and mediolateral sway velocity) in a normal and a single-leg standing position with the eyes open. Tests were performed at a 3-day interval among 35 volunteers aged 26.6 (SD 8.9) years. The coefficient of variation of the tests ranged from 5.4% to 8.7%. Two (normal standing) or three (single-leg standing) trials were performed per session, and the best result was used as an outcome variable.

Takala et al (1997) reported that, with the use of a custom-made force platform, sway velocity had the best day-to-day reproducibility and stability over time (9 months) among working people aged 38.7 years (n=9), the standard

deviation (SD) being 10.9. The other sway parameters studied were maximum lateral and anterior-posterior displacement, mean amplitude, mean sway frequency and sway area. For most of the items the mean differences in the parameters over time were less than 5-10% of the measured values. Day-to-day values of the ICC for sway velocity in a two-foot stance with the eyes open were 0.56 (mediolateral sway) and 0.50 (anteroposterior sway), the corresponding values for the eyes-closed condition being 0.46 and 0.54, respectively (Takala et al 1997). Single leg standing gave the following ICC values: 0.64 (lateral sway) and 0.72 (anteroposterior sway) for the right foot and 0.50 and 0.46, respectively, for the left foot. The ICC values for long-term stability were at about the same level or a little higher for some parameters. During the one-foot tests, the subjects were allowed to repeat the test three times if they failed the test; otherwise one repetition was performed.

Corriveau et al (2000) concluded that at least four trials of the COP minus COM variable are required to provide reliable results for postural balance among healthy people over the age of 60 years ($n=7$). Their outcome variable was the average of four trials. It has also been shown that, among healthy navy recruits and hospital staff (20-54 years, $n=60$), a longer time (≥ 17 days) between 10 repeated postural balance tests was less likely to produce a learning effect (Nordahl et al 2000). The other time intervals studied averaged 11, 31 and 115 days. According to Le Clair and Riach (1996), the best test-retest reliability is obtained for postural sway parameters at 20- and 30-s trial durations (subjects aged 19-32 years, $n=25$). They studied the reliability of five different test durations (i.e., 10, 20, 30, 45 and 60 s) and 10 s proved to be the least reliable.

Dynamic stability

High ICC values (0.88-0.93) were reported for a dynamic stability test (balance master) that involved weight shifting to eight targets positioned in an ellipse (Brouwer et al 1998). Young volunteers aged 24 (SD 3.2) years ($n=33$) performed tests on three occasions at 1-week intervals. For a sample of voluntary subjects aged 17-55 years, the results of a dynamic stability test (Good Balance) (to move the COP actively to follow a circle shown on a screen) improved systematically (paired T-test) in the second trial (Hofmann 1988). In this case, the possible effects of learning needed to be determined by quantifying actual baseline levels and the stability of the test over a longer period of time. Furthermore, Hirvonen et al (2002) found ICC values of 0.93-0.96 for a dynamic stability test (to move COG marker from the central target to the eight peripheral targets) with a custom-made force platform. Healthy subjects (aged 16-54 years, $n=23$) repeated the tests five times (4 practice trials and 1 test trial at each session) at different time intervals (1-12 days). The length of the time interval between the test occasions did not have a significant effect on test

reliability, whereas two to four parameters showed learning effects between the first and fourth and first and fifth test sessions (Hirvonen et al 2002).

Functional balance

Rinne et al (2001) studied the ICC values and LoA of tandem walking forwards, tandem walking backwards and standing on a bar among 25 healthy volunteers aged 36-72 years. The test-retest and interrater reliabilities were 0.91 and 0.88, 0.85 and 0.96, and 0.92 and 0.96, respectively. The tests were performed in three different sessions at 1-week intervals. All the balance tests showed some learning effect; however, the authors considered the LoA for tandem walking forwards and tandem walking backwards to be reasonable, 2 and 3 s, respectively. Furthermore, for a stratified sample of firefighters (aged 34-54 years, $n=50$) the test-retest reliability between two functional balance tests (walking as quickly and controlledly as possible on a wooden plank) repeated at 1-week intervals was 0.77 ($p < 0.001$) according to Pearson's correlation coefficient (Punakallio et al 1997a). Furthermore, the reliability of a dynamic balance test (walking on a 5-m long track while stepping only on two pads and standing on one foot, the empty pad being retrieved from behind and placed ahead so that the subject could proceed) at 1-week intervals was 0.90 (performance time) and 0.71 (loss of balance) for 57 healthy male volunteers aged 38-57 years (Räty et al 2002).

In most cases the star excursion balance test (a grid on the floor with eight lines extending at 45 degree increments from the center of the grid in which the subject maintains a single-leg stance while reaching with the other leg to touch as far as possible along a line) showed high intratester (ICC 0.78-0.96, SEM 1.8-3.4 cm) and intertester (ICC 0.35-0.93, SEM 2.3-5.0 cm) reliability among 16 recreationally active volunteers aged 21.3 (SD 1.3) years (Hertel et al 2000). At two testing sessions with a 1-week interval the subjects performed three trials (one practice trial) for both legs in each direction. There were significant learning effects, however, for the repetitive trials of four of the eight excursion directions, and trials 7-9 had the longest excursions in all directions.

3. THEORETICAL FRAMEWORK OF THE STUDY

The theoretical framework of this study is based on, and has been modified from, the systems approach of Shumway-Cook and Woollacott (1995). In the present framework balance control is considered to be an interaction between the individual capacities of a worker, the work task with its inherent balance demands, and the demands of the work environment on balance (Fig. 2).

The high balance demands of the work and unpredictable and rapidly changing work conditions make balance control and maintenance challenging for a worker in physically demanding jobs. Adequate balance control in relation to task and environmental demands may prevent accidents and injuries, and may also support and promote health, safety and work ability. Therefore, in addition to the worker's individual capacities, the aspects of the work task and the environment should be characterized when balance abilities are studied with various tests.

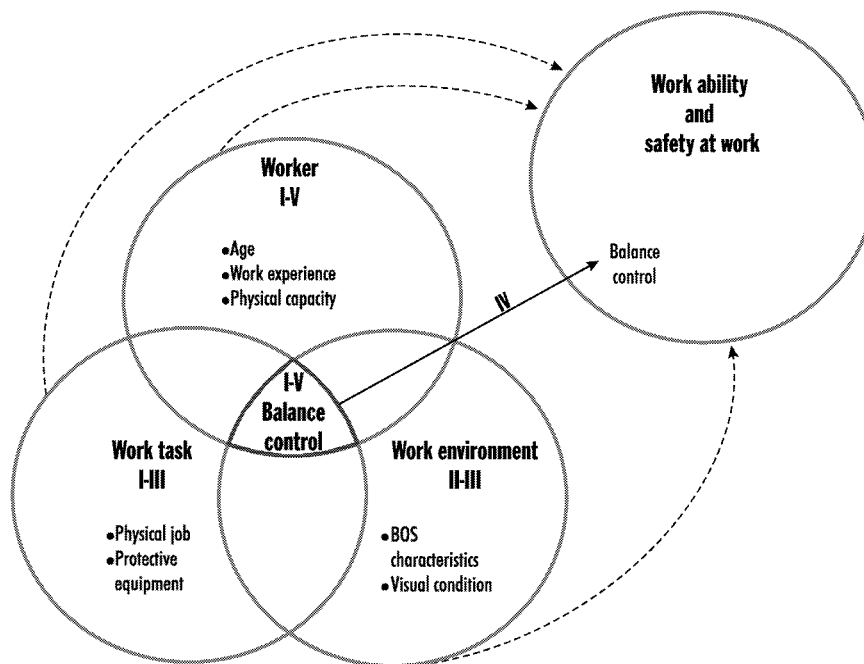


Figure 2. The framework of the study (modified from Shumway-Cook and Woollacott 1995). The Roman numerals represent the present studies, as based on the framework. The dotted lines indicate relations not measured in this study (BOS=base of support).

4. AIMS OF THE STUDY AND STUDY DESIGN

4.1 Aims of the study

The purpose of this study was to investigate the associations between balance abilities and aspects of job demands, work ability and safety among different aged workers in physically demanding jobs, and, particularly, those in fire and rescue work. The associations between individual characteristics, such as age and occupation, with balance abilities were studied. The task-related and environmental factors, such as the effects of FPE, visual conditions and slippery surfaces, were also studied in association with the balance abilities of firefighters. The methodological aim was to evaluate the reliability of the balance tests and their predictive value in respect to perceived work ability.

The aims of the study can be specified in the form of the following questions:

1. Do postural and functional balance abilities differ among different aged workers from different physical occupations, and do balance abilities differ between workers in different occupations? (I)
2. Does fire-protective equipment affect functional and postural balance abilities, and do the influences differ in two visual conditions and between younger and older firefighters? (II)
3. Are balance abilities, muscular capacities and age associated with slip and fall risk in walking experiments with firefighters wearing fire-protective equipment? (III)
4. Do postural, functional and perceived balance abilities predict perceived work ability and physical work ability? (IV)
5. What is the reproducibility of the dynamic stability test and functional balance test, and what is their test-retest stability after 2 months? (V)

4.2 Study design

The study design varied depending on the specific objectives of Studies I-V. Cross-sectional measurements were applied in Studies I-III, and longitudinal designs were used in Studies IV and V (Table 3).

5. MATERIALS AND METHODS

5.1 Subjects

The subjects of the overall study comprised firefighters (I-V), construction workers (I), home care workers (I) and nursing staff (I) (Table 3). The data on firefighters are based on a 3-year follow-up of the health and physical and mental capacity of Finnish professional firefighters (3-year study) (Punakallio et al 1999). Most of the data in this study are from the second cross-section in 1999 (Fig. 3).

At baseline in 1996, 210 professional male firefighters were selected from central and southern Finland by stratified sampling. Samples were obtained from all professional, operational firefighters in the age groups of 30-34 (n=254), 40-44 (n=208) and 50-54 (n=120) years in 1996 and were from 28 fire departments situated within 100 km of Helsinki (southern Finland) or 150 km of Kuopio (central Finland). About 9 out of 10 of the selected firefighters (89%) participated in the balance tests and responded to the questionnaire.

Table 3. Number of subjects (n), age and occupation of the subjects, the participation rate of the eligible subjects, the sampling method, and the design for Studies I-V.

Study	N	Age (years), mean (SD) range	Occupation	Participa- tion rate, %	Entrance to the study	Study design
I	69	41.7 (7.7) 33-56	Firefighter	87	Stratified sampling	Cross- sectional
	52	39.9 (8.7) 23-56	Construction worker	84	All from one occupational health care unit	Cross- sectional
	51	41.9 (10.5) 26-61	Nursing staff	85	Stratified sampling	Cross- sectional
	66	46.2 (8.5) 28-61	Home care worker	88	All from 10 work units	Cross- sectional
II, III, V	29	42.3 (7.7) 33-56	Firefighter	97	Volunteers	Cross- sectional (II- III) Longitudinal (V)
IV	135	40.7 (7.5) 30-54	Firefighter	82	Stratified sampling	Longitudinal

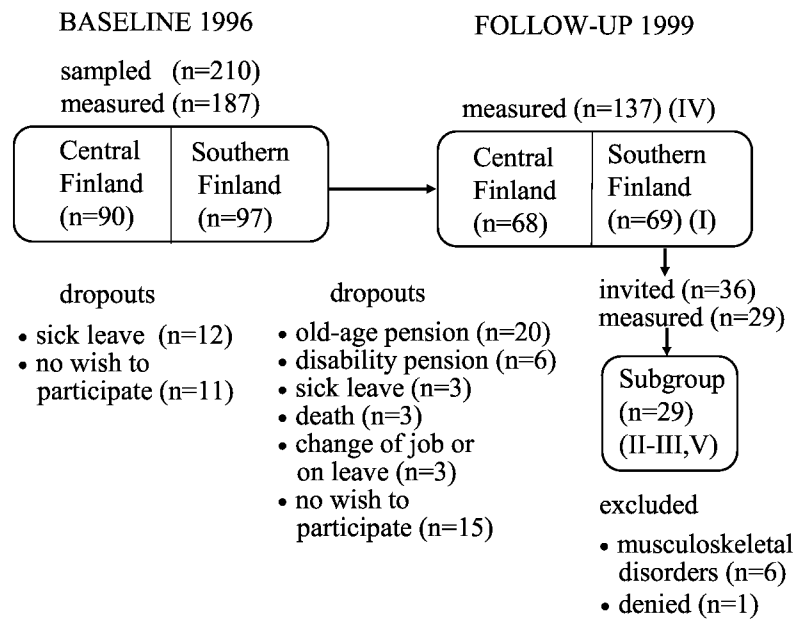


Figure. 3. Sampling, number of subjects (n) and dropouts in different phases and parts of the 3-year study of firefighters.

5.1.1 Study of balance abilities among different aged workers in physically demanding jobs (I)

In addition to firefighters, Study I included construction workers, nursing staff and home care workers (Table 3). The construction workers came from both private companies and the municipal sector of the city of Lappeenranta. Their balance was measured when they took part in their periodic health check-ups in an occupational health care unit. Municipal home care workers, who cared for elderly people in private or institutional homes, from 10 entire work units in the city of Helsinki formed the initial sample of home care workers (Pohjonen 2001a). Their balance tests were carried out at the time of their 5-year follow-up tests for physical fitness. Altogether 60 municipal nursing workers were selected by stratified sampling from 216 nursing workers from an old people's home in the city of Helsinki (Pohjonen et al 2003). The data on firefighters came from those in southern Finland who participated in the follow-up tests (in 1999) in the 3-year study (Fig. 3, Table 3).

5.1.2 Studies of balance and slip risk with fire-protective equipment and the reliability of the balance tests (II, III, V)

In Studies II, III and V, the subjects were a subgroup (n=29) of the 69 firefighters from southern Finland who participated in the follow-up tests of the 3-year study (Fig. 3, Table 3). A total of 36 male firefighters in two age groups (33-38 and 43-56 years) were asked to volunteer for the studies. Six of the firefighters over 50 years of age were excluded because they had had low-back pain during the preceding year, had acute low-back or other musculoskeletal pain or had disorders that might have been exacerbated by the activities in the studies. After the selection process, one young firefighter refused to participate, and the final sample included 29 firefighters.

5.1.3 Study of the predictive value of the balance tests (IV)

In study IV the subjects were firefighters who participated in balance tests in 1996 and responded to the questionnaires in 1996 and 1999 in the 3-year study (Fig. 3). The study sample also included six firefighters who retired on a disability pension during the 3-year follow-up. They were included in the category of poor work ability in 1999. Furthermore, eight firefighters who participated in the laboratory tests did not respond to the questionnaire. Therefore, the final number of subjects was 135 (Table 3).

5.2 Methods

5.2.1 Balance measurements (I-V)

Functional balance

The balance tests and variables, from Studies I-V, are shown in Table 4. Functional balance was measured by a test in which a subject walked forwards, backwards and turned 180 degrees in the middle on a 2.5-m long, 9-cm wide and 5-cm thick wooden plank (Fig. 2, Study V) (Punakallio et al 1997a). He or she was instructed to walk as quickly as possible without falling off the plank or touching the floor, as these movements were considered errors. It was also an error if the subject turned around before or after the mid-area of the plank or if the subject did not step on the footprints at the ends of the plank. The performance time and the number of errors were recorded. The sum variable was also calculated by summing the time and the number of errors, where one error was assigned a value of 1 s.

Table 4. Variables measured in Studies I-V.

Variable	Study	Reference
Balance tests		
<i>Functional balance</i>		
Performance time (s)	I-V	Punakallio et al 1997a
Performance time (s) + errors	I-V	
Errors (number)	I-V	
<i>Dynamic stability</i>		
Performance time (s)	III, V	Metitur 2001
Distance traveled by COP (mm)	III, V	
<i>Postural balance</i>		
Normal standing (EO, EC) 40 s		Era et al 1996, Metitur 2001
Mediolateral velocity (mm/s)	I (EO), II	
Anteroposterior velocity (mm/s)	I (EO), II	
Velocity moment (mm ² /s)	I (EO), II, III	
Tandem standing (EO) 20 s		Era et al 1996, Metitur 2001
Mediolateral velocity (mm/s)	I	
Anteroposterior velocity (mm/s)	I	
Velocity moment (mm ² /s)	I	
Normal standing (EO, EC) 30 s		Starck et al 1993, Takala et al 1997
Mean sway velocity (mm/s)	IV	
Mean sway amplitude (mm)	IV	
Perceived balance (1-5)	IV	Lusa-Moser et al (unpublished data), Punakallio et al 1997a
Risk of slipping and falling		
Sliding distance of the foot (cm)	III	Grönqvist 1995
Work ability		
Work ability index (7-49)	IV	Tuomi et al 1991, 1998
Perceived physical work ability (1-5)	IV	
Work experience (years)	I-V	
Physical activity		
Frequency (not at all-≥3 times/week)	I-V	Aromaa et al 1989
Muscular capacities		
Sit and reach (cm)	III	Pollock and Willmore 1990
Squatting (repetitions/60 s)	I, III	Lusa 1994
Squatting (repetitions/30 s)	I	Aura 1994
Sit-up (repetitions/60 s)	III	Lusa 1994
Trunk extension strength (N)	III	Viitasalo et al 1977
Knee extension strength (N)	III	Viitasalo et al 1985
Aerobic capacity		
VO _{2max} (ml·min ⁻¹ ·kg ⁻¹ ; l·min ⁻¹)	II	
Anthropometrics		
Body height (cm)	I-V	
Body weight (kg)	I-V	
Body mass index (kg·m ⁻²)	I-V	
EO=eyes open, EC=eyes closed, VO _{2max} =maximal oxygen consumption		

EO=eyes open, EC=eyes closed, VO_{2max}=maximal oxygen consumption

Postural balance

In Studies I-III postural balance was measured using the Good Balance measurement device of Metitur Ltd (Metitur 2001), and in study IV postural balance tests were carried out on a custom-made force platform (Starck et al 1993, Takala et al 1997). The outputs of the instruments were voltage signals from force transducers that registered vertical forces and anteroposterior and mediolateral moments in relation to the central axis of force platform. The force transducers were situated in each corner of the platforms. The Good Balance measurement system consisted of an equilateral triangular force platform, with a side length of 800 mm, connected to a computer through an electronic unit, which included a 3-channel amplifier and a 12-bit analogue-to-digital (A/D) converter. The analogue signals were amplified and then digitized with a sampling frequency of 50 Hz and passed to the computer through a serial (com) port. Then the data were filtered and processed in digital form by the software. The data of each channel were filtered separately using two different filters: a 7-point median filter and lowpass infinite impulse response filter with a cut-off frequency of 20 Hz. The median filter removed or effectively reduced impulse noise, whereas high-frequency noise, caused by the measurement system and A/D conversion, was reduced by lowpass filtering (Aalto 1997).

The custom-made force platform consisted of two square metal plates, with a side length of 400 mm, placed horizontally and separated by force measuring elements (Starck et al 1993, Takala et al 1997). After amplification, 12-bit A/D conversion of the force signals was carried out, the signals being digitized with a sampling frequency of 40 Hz. Measurement noise was decreased by filtering signals digitally with a three-point median filter and thereafter with a 16-order finite impulse response filter with a cut-off frequency of 10 Hz.

From the filtered data the x- and y-coordinates of the COP displacements during the measurement time were then calculated following the procedures reported by Hoffmann (1998) (Good Balance) and Takala et al (1997) (custom-made platform). In the Good Balance system on the basis of the COP coordinates three postural balance outcome variables were finally calculated: anteroposterior sway velocity (mm/s), mediolateral sway velocity and velocity moment (mm^2/s) (Table 4). Sway velocities were calculated by dividing the total COP displacements in each direction by the measurement time (s). The velocity moment refers to first moment of velocity calculated as the mean area covered by the movement of the COP during each second of the test (Era et al 1996). The calculation of the velocity moment took into account both the distances from the geometric midpoint of the whole test and the speed of movement during the same period (Era et al 1996). All analyses involving the Good Balance force platform, were carried out by centralizing the data of each test with respect to its own midpoint. The sway parameters of the custom-made

force platform were related to the arithmetic mean point, which was calculated by averaging the mediolateral and anteroposterior displacement of the COP over the whole measurement period. The parameters calculated, when the custom-made platform was used, were the mean sway velocity (mm/s) and the mean sway amplitude (mm) (the anteroposterior and mediolateral components of sway were analyzed together) with eyes open and closed. The mean amplitude was the mean distance between the sampling points and the arithmetic mean point.

The following measurements were carried out while the subject was standing on the force platform: 1) normal standing for 40 s (Good Balance) or 30 s (custom-made platform) with the eyes open, the hands placed on hips and the gaze fixed on a cross on the opposite wall at eye level, 2) normal standing as before, but with the eyes closed, 3) tandem standing for 20 s (Good Balance) with the eyes open and the feet positioned heel-to-toe along the midline of platform, the subject being instructed to stand as immobile as possible. Table 4 shows the variables measured with each force platform technique in Studies I-V.

Dynamic stability

Dynamic stability was also assessed using the Good Balance measurement system (Metitur 2001). In the test, the monitor for visual feedback was on the table in front of the subject. Eight targets were shown in a circle on the computer monitor (Fig. 1, Study V). The idea of the measurement was to move the COP through the targets. The subject was instructed to reach the targets as quickly and as accurately as possible and to avoid unnecessary and uneconomic movements. The performance time (s) (time used to complete the test) and the distance (mm) (the extent of the path traveled by the COP during the test) were measured. Dynamic stability and postural balance parameters were scaled according to body height in Studies I-III and V (Metitur 2001).

Perceived balance abilities

Perceived balance abilities in relation to the balance demands of work was inquired about in a questionnaire (Lusa-Moser et al unpublished data, Punakallio et al 1997a) using the following question: "Balance is needed especially in work in high and narrow places. How do you rate your current balance abilities with respect to the balance demands of your work?" The scale of the question ranged from 1 to 5: 1=very poor, 2=rather poor, 3=moderate, 4=rather good, 5=very good. Categories 1 through 2 (poor) were combined for further analysis, as were categories 4 and 5 (good). The results were also presented with categories 1 through 3 (poor-to-moderate) merged.

Anthropometrics, muscle capacities and cardiorespiratory capacity (Table 4) were also measured, and they were considered to be individual background

factors for balance. A detailed description of the measurements of balance and the other physical capacities are given in the original studies.

5.2.2 Balance and slipping tests with fire-protective equipment (II-III)

Fire-protective equipment

The FPE included a two-piece multilayer fire-protective suit that fulfilled the European standard (EN 469: 1995) (Committee for Standardization 1995). The subjects also wore Nordic-type middle and under clothing, rubber safety boots, a helmet and a tool belt, and they carried Dräger SCBA (Germany) with one steel air bottle worn on the back and a full-face mask. The mass of the FPE was 25.9 kg, of which the SCBA accounted for 15.5 kg.

Balance tests with and without the fire-protective equipment

After demonstrations of the balance tests, the subjects were allowed to practice once before the measurement. Each test and equipment combination was measured once. First, the subjects performed the baseline postural balance test with their eyes open and in sportswear (t-shirt, shorts and barefoot). The test was immediately repeated with the eyes closed. Second, the baseline functional balance test was carried out. Third, the functional balance test was performed 1) with the full-face mask of the SCBA, 2) with the rubber safety boots, and 3) with the SCBA. Finally, the functional and postural balance tests were carried out with the FPE.

Slipping tests with the fire-protective equipment

Slipping tests were carried out on a straight 8-m long path. In one area (400 × 600 mm), covered by stainless steel, water and detergent (0.5 % by weight sodium lauryl sulfate solution) or glycerol (85 % by weight) were spread on the path. The first half of the track was covered with a rubber carpet. The subject wore a safety harness fastened into a rail above the track.

The length of each slip (i.e., horizontal sliding distance of the foot in the walking direction in centimeters) was assessed with one high-speed camera system. Video-recordings were used to estimate the seriousness of the slipping incidents. The slips were classified into the following four categories according to the efforts of the walkers to restore their balance by corrective movements (Hirvonen et al 1994): 1) no observable slipping (the length of the slip was less than 5 cm or the subject made no corrective movement), 2) controlled slip (the subject swayed and made controlled corrective movements and would probably have regained his balance even without the safety harness), 3) vigorous slip (the

subject slipped and staggered significantly; the corrective movements were vigorous; without the harness a loss of balance would have been possible), and 4) extremely vigorous slip (the subject lost his balance and was suspended by the safety harness).

Each subject performed four slipping tests under the following conditions: 1) dry path, walking speed 100 steps/min, 2) path spread with water and detergent, walking speed 100 steps/min, 3) path spread with glycerol, walking speed 100 steps/min, and 4) path spread with glycerol, walking speed 120 steps/min. The walking speeds were defined by a metronome. The tests were performed in the same order with every subject, but none of them were aware of the slipperiness of the path in advance. The subjects were asked to walk at the given walking speed as naturally as possible throughout the tests.

5.2.3 Questionnaires (I-V)

Perceived work ability

Perceived work ability was inquired about with the work ability index (WAI) using a questionnaire (Tuomi et al 1991, 1998). The WAI is a sum variable based on the subjective estimations of work ability in relation to physical work ability (PWA) and mental job demands. It also includes questions on current diseases, estimated work impairment due to diseases, sick-leave days during the past 12 months, prognosis of work ability after 2 years and mental resources. The WAI score ranges from 7 to 49 and is divided into four categories of work ability as follows: poor (7 to 27 points), moderate (28 to 36 points), good (37 to 43 points), and excellent (44 to 49 points). The cut points for poor and excellent work ability were chosen from the 15th percentile of the index distribution of the total studied population, and the moderate and good classifications were the number of points dividing the distribution of the WAI in half (Tuomi et al 1985, Tuomi et al 1998). Furthermore work experience and physical activity were inquired about with the use of questionnaires in (Table 4).

5.3 Assessment of the predictive value of the balance tests (IV)

Work-related validity was assessed by examining the predictive value of the results of the balance tests and the perceived balance abilities in respect to the WAI and PWA. There were no classifications available for the functional and postural balance tests. Therefore with the continuous predictive variables, the subjects were divided into the categories of "good", "average" and "poor" using tertiles of the variables as the cut points. In the functional balance test, no errors were categorized as "good", one error was "average" and more than one error was "poor" (Table 10).

5.4 Assessment of reliability (V)

In the evaluation of the trial-to-trial reproducibility, the functional balance and dynamic stability tests were repeated six consecutive times in one test period with a break of a few seconds between the trials. The test-retest stability was studied over a longer period by carrying out the balance tests again about 2 months later. Stability between the test sessions was calculated using both the last trial in each trial combination and the best values of the first to second, first to third, first to fourth, first to fifth, first to sixth and third to sixth consecutive trials as the outcome variables. From these two, the outcome variable with the highest test-retest stability was chosen as the final outcome variable.

5.5 Statistical methods

In Study I, one- and two-way general linear models were used to analyze the effects of age and occupation on the balance tests. Furthermore, in each occupational group, multiple comparisons with Tukey's method were made to determine the significant differences between the age groups. If differences were found between occupations, they were further evaluated separately among the "male-specific" occupations and the "female-specific" occupations. These models were adjusted for the muscular endurance of the legs, physical activity and work experience.

In Study II, linear mixed models (analysis of variance with repeated measurements) were used to study the effect of FPE, age, and eye closure on the results of balance abilities. The interaction of FPE and age, eye closure and age, as well as the interaction of FPE, age, and eye closure, was added to the models. The models were fitted using the PROC MIXED procedure in the Statistical Analysis System, SAS Version 8.2 (SAS Institute 1999).

In Study III Student's t-tests were applied to determine the statistical significance for age, balance and muscle capacities between the subjects as classified by sliding distance (< 5 cm versus ≥ 5 cm).

In Study IV, logistic regression analysis with proportional odds assumption (Peterson and Harrell 1990) was used when the associations between the outcome (WAI and PWA determined in 1996 and 1999) and predictive variables (functional and postural balance and perceived balance in 1996) were examined. The final models (outcome in 1999) were estimated by adding the previous outcome in 1996 to the models (i.e., transition models) (Diggle et al 1994). In addition, the models were adjusted for age. Odds ratios (OR) and 95% confidence intervals (CI) were calculated.

In Study, V two-way general linear mixed models (analysis of variance with repeated measurements) were used to assess the systematic error between six consecutive trials and between the test sessions with an interval of 2 months.

Stability between the test sessions was calculated using both the last trial in each trial combination and the best values of the first to second, first to third, first to fourth, first to fifth, first to sixth and third to sixth consecutive trials as outcome variables.

The absolute reliability between trial-to-trial and between test-retests in Study V was expressed using Bland and Altman's 95% LoA (Bland and Altman 1986, Atkinson and Nevill 1998). The LoA was calculated as follows. First, the differences (=bias) and the standard deviation between the tests were calculated, and then the standard deviation of the differences was multiplied by 1.96 to obtain the 95% random error component. The reproducibility between trial-to-trial and stability between test-retests over time was estimated by the ICC with 95% CI. The ICC values were classified according to Fleiss (1986), with the exception that the excellent category (>0.75) was divided into two categories, as follows: >0.90 excellent, >0.75 - 0.90 good, 0.40 - 0.75 modest and <0.40 poor reproducibility.

Statistical analyses were performed using the Statistical Analysis System, SAS Version 8.2 or 6.2 (SAS Institute 1989 and 1999) and SPSS 11.5 (SPSS Inc 1997). The statistical significance was defined as $p < 0.05$.

6. RESULTS

6.1 Relationship between balance abilities and the age and occupation of workers in physically demanding jobs (I)

In general, age and occupation had a significant effect on functional balance ($F=15.0$, $p=0.0001$ and $F=69.2$, $p=0.0001$, respectively). Among the firefighters, construction workers and home care workers, the younger and middle-aged subjects were significantly ($p=0.028$ - 0.001) faster, and they made fewer errors than the older ones (Table 3, Study III). About one-third of the male subjects (25% of the construction workers, 36% of the firefighters) and 54-57% of the female subjects made one error or more in the test. Furthermore, the construction workers had significantly better functional balance than the firefighters. The home care workers also performed faster in the test than the nursing workers (Fig. 4). These differences remained significant when the muscular endurance of the legs, the intensity of physical exercise and work experience were used as covariates.

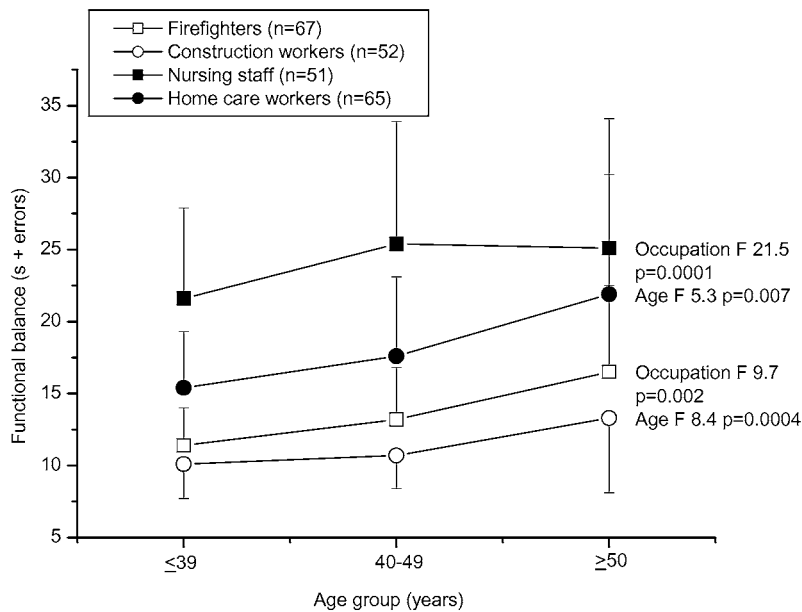


Figure 4. Functional balance (means and SD) of the three age groups of subjects from different occupations and the significance between balance and age and balance and occupation.

Significant effects due to age were observed for the mean mediolateral and anteroposterior sway velocity in normal ($F=4.5$, $p=0.010$, and $F=3.9$, $p=0.020$, respectively) and tandem ($F=13.8$, $p=0.0001$, and $F=3.8$, $p=0.021$, respectively) standing positions. The older subjects in each occupation tended to sway the most. The differences in the mean velocity between the occupational groups in the mediolateral direction in the normal standing position were also significant ($F=5.4$, $p=0.006$) (Tables 5 and 6).

The differences between the different aged subjects were significant for velocity moment as well ($F=3.8$, $p=0.020$, for normal standing; $F=8.2$, $p=0.0004$, for tandem standing). The older subjects tended to sway the most (Table 5 and 6). During tandem standing, the home care workers tended to have lower values than the other occupational groups. The difference was significant in a comparison with the velocity moment of the nursing workers ($p=0.040$), but the difference disappeared when the model was adjusted for muscular endurance of the legs.

Table 5. Postural balance of the different occupational groups in the normal standing position by age and the significant differences between the age groups.

Variable / occupation	Age group (years)			P < 0.05
	≤39 (1)	40-49 (2)	≥50 (3)	
Mediolateral velocity (mm/s)				
Firefighters	3.2 (0.9)	2.9 (0.8)	4.6 (2.5)	1-3, 2-3
Nursing staff	4.5 (2.4)	3.9 (1.2)	4.9 (1.5)	
Home care workers	4.6 (1.4)	4.6 (1.6)	3.7 (1.1)	
Anteroposterior velocity (mm/s)				
Firefighters	5.0 (0.9)	5.5 (1.3)	6.6 (1.6)	1-3, 2-3
Nursing staff	5.6 (2.7)	5.6 (1.8)	7.1 (2.6)	
Home care workers	5.4 (2.0)	5.6 (2.5)	5.6 (2.0)	
Velocity moment (mm ² /s)				
Firefighters	7.7 (3.4)	8.4 (4.6)	14.7 (9.1)	1-3, 2-3
Nursing staff	8.0 (5.0)	10.2 (6.4)	15.7 (8.0)	1-3
Home care workers	10.3 (4.0)	11.5 (6.5)	9.0 (3.6)	

Table 6. Postural balance of the different occupational groups in the tandem standing position by age and the significant differences between the age groups.

Variable / occupation	Age group (years)			P < 0.05
	≤39 (1)	40-49 (2)	≥50 (3)	
Mediolateral velocity (mm/s)				
Firefighters	16.1 (3.6)	17.2 (3.3)	21.8 6.6	1-3, 2-3
Nursing staff	15.9 (4.1)	22.5 (2.9)	24.3 8.5	1-2, 1-3
Home care workers	14.7 (2.6)	22.1 (2.2)	19.2 4.1	1-2, 1-3
Anteroposterior velocity (mm/s)				
Firefighters	13.8 (3.5)	13.5 (3.0)	17.7 4.0	1-3, 2-3
Nursing staff	13.4 (3.1)	16.3 (4.4)	17.4 8.6	
Home care workers	12.1 (3.1)	13.5 (3.7)	13.6 3.0	
Velocity moment (mm ² /s)				
Firefighters	59.4 (31.4)	55.2 (25.7)	85.9 36.9	1-3, 2-3
Nursing staff	57.5 (30.1)	79.9 (34.3)	88.3 59.1	
Home care workers	38.9 (18.7)	55.2 (23.2)	62.5 26.3	1-2, 1-3

6.2 Effects of fire-protective equipment on the balance abilities of younger and older firefighters (II)

The postural balance was significantly poorer in the tests with the FPE than in the baseline tests with the sportswear (Fig. 5a-c, Table 7). Age had a significant effect on the anteroposterior velocity, whereas eye closure increased postural sway significantly for all the variables. The interaction of FPE, age and eye closure was significant for the velocity moment, and it was nearly significant for the mediolateral velocity of postural sway (Table 7). The harmful effect of the equipment on postural balance with the eyes closed was greater for the older firefighters ($p=0.033$ for mediolateral velocity and $p=0.005$ for velocity moment) than for the younger firefighters ($p=0.737$ for mediolateral velocity and $p=0.893$ for velocity moment.)

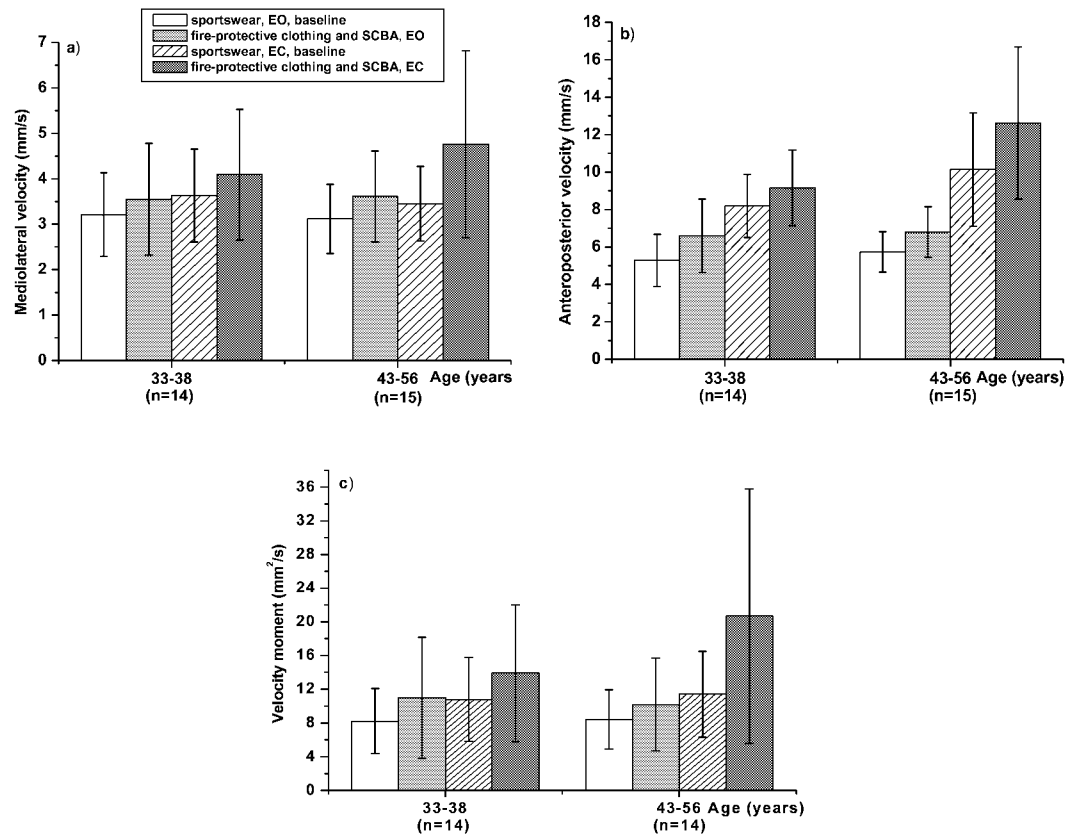


Figure. 5a-c. Postural balance (mean and SD) of two age groups with fire-protective clothing and SCBA (self-contained breathing apparatus) and in the baseline tests with the sportswear (EO=eyes open, EC=eyes closed).

Table 7. Effects of fire-protective clothing (FPC) with SCBA (self-contained breathing apparatus), age, eyes closed (EC) and their interaction on postural balance (n=29). F and p-values were determined in an analysis of variance with repeated measurements.

Variable	Mediolateral velocity		Anteroposterior velocity		Velocity moment	
	F	P	F	P	F	P
FPC+SCBA	11.3	0.002	31.2	<0.0001	12.1	0.0001
Age	0.12	0.736	5.47	0.027	0.74	0.396
EC	22.0	<0.0001	101.2	<0.0001	20.7	0.001
FPC+SCBA·age	1.59	0.218	0.94	0.340	0.90	0.352
EC·age	1.02	0.322	10.2	0.004	3.85	0.060
FPC+SCBA·age·EC	2.56	0.096	1.33	0.281	4.48	0.021

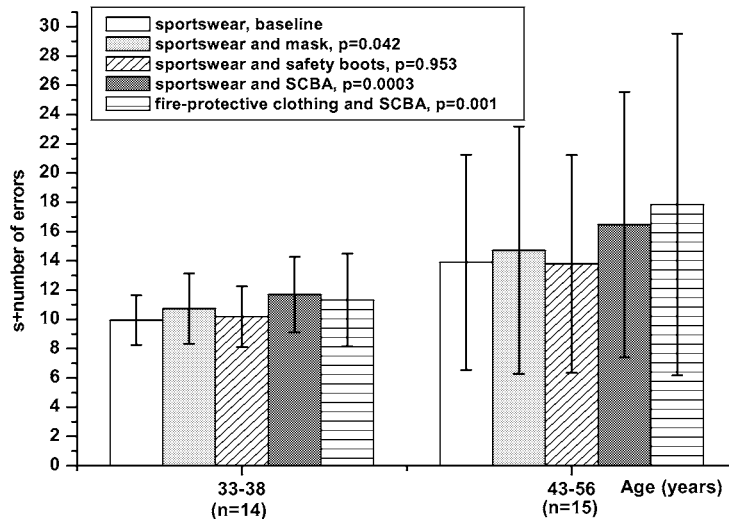


Figure 6. Functional balance (mean and SD) of two age groups of firefighters and the significance of the different equipment combinations in the comparison with the baseline test (sportswear only). (SCBA=self-contained breathing apparatus).

The use of the FPE impaired functional balance significantly ($F=5.5$, $p=0.0002$) as well. With the exception of the safety boots, the different combinations of equipment had a significant effect on functional balance (Fig. 6). The interaction of the FPE and age was, however, not statistically significant (Fig. 6). The age-related differences in functional balance with and without equipment were close to statistical significance ($p=0.065$).

6.3 Balance, muscular capacities and age in association with slip and fall risk (III)

When the path was spread with water and detergent, altogether two subjects in the older age group slipped 4 cm, and the sliding movement and balance was well controlled. Every subject slipped in the tests with glycerol at both walking speeds. The average values of the sliding distances were 9.7 (SD 9.1) cm (100 steps/min) and 15.6 (SD 18.2) cm (120 steps/min) in the 33-to-38-year age group. The corresponding values were 10.8 (SD 15.3) cm and 18.0 (SD 18.6) cm in the 43-to-56-year age group.

Half of the subjects slipped more than 5 cm in the test. About two-thirds (37/54) of the slip incidents were well controlled or needed no corrective movements (Table 8).

Table 8. Seriousness of the slipping incidents and the length of slips on glycerol in the age groups of firefighters at the walking speeds of 100 and 120 steps/min. The values are the number of subjects in each category (n) with the ranges of the slip distances in parentheses.

Seriousness of the slips	Walking speed (steps/min)			
	100	120	100	120
	Age group (years)			
	33-38	43-56		
	n (slip distance range, cm)	n (slip distance range, cm)		
No corrective movement	1 (2)	1 (2)	2 (2)	1 (2)
Controlled slip ^a	8 (1-14)	7 (2-20)	9 (2-11)	7 (3-8)
Vigorous slip ^b	5 (13-20)	2 (20-50)	3 (40-50)	2 (15-40)
Extremely vigorous slip ^c	0	1 (50)	1 (25)	4 (30-50)
	n total 14	n total 11	n total 15	n total 14

^a Balance could also be regained without the safety harness.

^b Loss of balance is possible without the safety harness.

^c Balance was lost and the subject was suspended by the safety harness.

The subjects whose sliding distance with glycerol was ≥ 5 cm performed significantly poorer in the dynamic stability test than those who slipped < 5 cm when the walking speed was 100 steps/min (Table 9).

Table 9. Age, body mass index, balance and muscular capacities as classified by sliding distance when the path was spread with glycerol and the walking speed was 100 steps/min. (EO=eyes open, EC=eyes closed).

Characteristic	Sliding distance		P-value
	<5 cm (n=14)	≥5 cm (n=15)	
Age (years)	Mean (SD) 43.6 (8.5)	Mean (SD) 41.4 (6.9)	
Body mass index (kg·m ⁻²)	27.0 (3.1)	26.2 (1.9)	
Balance			
Functional balance (s)	10.7 (2.2)	12.2 (7.7)	
Functional balance (s+errors)	11.0 (2.2)	12.9 (7.7)	
Functional balance (errors)	0.4 (0.6)	0.7 (0.7)	
Dynamic stability (mm)	1393 (379)	1902 (565)	0.0094
Dynamic stability (s)	15.1 (2.3)	18.8 (4.3)	0.0095
Postural balance (EO) (mm ² /s)	7.5 (3.1)	9.2 (4.0)	
Postural balance (EC) (mm ² /s)	10.4 (3.9)	11.8 (5.9)	
Perceived balance (1-5)	3.7 (0.7)	3.4 (0.9)	
Muscular capacities			
Sit and reach (cm)	32.9 (8.9)	29.9 (10.7)	
Squatting (repetitions/60 s)	28.4 (5.8)	24.8 (8.9)	
Sit-up (repetitions/60 s)	35.4 (7.7)	34.3 (6.7)	
Trunk extension strength (N)	795 (143)	866 (149)	
Knee extension strength (N)	532 (122)	494 (128)	

6.4 Predictive value of balance with respect to the perceived work ability of firefighters (IV)

During the 3-year follow-up the proportion of the subjects whose WAI category decreased was 34% (n=45), and the proportion of those whose WAI was poor increased from 6% to 16%. The WAI category was increased for 21 subjects (17%) (Table 2, Study IV). Correspondingly, PWA decreased for 30% of the subjects (n=39) and increased for 5% (n=7) (Table 3, Study IV).

At baseline in 1996, when the models were adjusted for age, the poor PWA category was associated with poor results in the majority the balance tests used (Table 10). In addition, poor results for performance time in the functional balance test (OR 2.2, CI 0.9-5.4) and time (s) + errors (OR 2.4, CI OR 0.9-5.4) and poor-to-moderate perceived balance (OR 9.8, CI 3.8-24.9) was associated with a lower WAI category at baseline (Table 10). The postural sway velocity and the sway amplitude with the eyes open were excluded both from Table 10 and from the further analyses because the OR values were not significant in any category.

Table 10. Age-adjusted odds ratios (OR) and 95% confidence intervals (CI) for balance abilities associated with the work ability categories at baseline in 1996 (n=135). (EC=eyes closed).

Predictor	Work ability index 1996		Physical work ability 1996	
	OR	CI	OR	CI
Functional balance (s)				
Good ≤ 10.6	1.0		1.0	
Average $>10.6 \leq 13.1$	2.3	1.0-5.4	5.2	2.0-13.4
Poor >13.1	2.2	0.9-5.4	3.2	1.2-8.5
Functional balance (errors)				
Good <1	1.0		1.0	
Average 1	0.7	0.3-1.5	1.5	0.7-3.2
Poor >1	1.0	0.3-2.9	2.3	0.8-7.0
Functional balance (s+errors)				
Good ≤ 11.1	1.0		1.0	
Average $>11.1 \leq 14.6$	1.2	0.5-5.4	2.5	1.0-5.8
Poor >14.6	2.4	0.9-5.4	3.8	1.4-10.8
Sway velocity EC (mm/s)				
Good ≤ 19.2	1.0		1.0	
Average $>19.2 \leq 24.7$	1.9	0.8-4.8	2.5	1.0-6.3
Poor >24.7	1.8	0.7-4.5	3.3	1.3-8.5
Sway amplitude EC (mm)				
Good ≤ 6.0	1.0		1.0	
Average $>6.0 \leq 7.5$	1.8	0.7-4.3	2.4	0.9-6.0
Poor >7.5	1.3	0.5-3.2	2.6	1.0-6.5
Perceived balance ^a				
Good 4-5	1.0		1.0	
Moderate 3	8.3	3.2-21.4	4.4	1.7-11.4
Poor 1-2	57.7	9.9-336	34.4	6.1-193
Perceived balance ^b				
Good 4-5	1.0		1.0	
Poor-to-moderate 1-3	9.8	3.8-24.9	5.5	2.2-13.7

^a The 95% CIs were very wide; ^b therefore the results were also computed using two categories.

The final predictive models were adjusted for age and also the baseline WAI category. Table 11 shows the predictors that were still statistically significant (i.e., poor categories in the functional balance test, sway amplitude with the eyes closed and perceived balance in 1996 indicated 3.6-, 2.3- and 9.5-fold risks, respectively, for a decline in the WAI during the 3-year follow-up). The results were also calculated so that the categories of poor and moderate were grouped together for perceived balance. Then poor-to-moderate perceived balance

showed a 2.4-fold risk (OR 0.9-6.6) for a decline in the WAI in comparison with good perceived balance abilities. Age and the baseline WAI category were powerful predictors of the WAI in 1999. The final models for PWA did not produce valid results because the PWA in 1996 and 1999 were strongly related.

Table 11. Odds ratios (OR) and 95% confidence intervals (CI) for the significant predictors of the Work Ability Index (WAI) after the follow-up. The final models were adjusted for age and baseline WAI (1996) (n=134), (EC=eyes closed).

Predictor	WAI 1999 Model 1		WAI 1999 Model 2		WAI 1999 Model 3	
	OR	CI	OR	CI	OR	CI
Functional balance (number of errors)						
Good <1	1.0					
Average 1	1.0	0.5-2.2				
Poor >1	3.6	1.0-12.7				
Sway amplitude (EC) (mm)						
Good ≤6.0			1.0			
Average >6.0≤7.5			2.7	1.0-7.2		
Poor >7.5			2.3	0.9-6.1		
Perceived balance						
Good 4-5					1.0	
Moderate 3					2.4	0.8-5.8
Poor 1-2					9.5	1.5-58.3
Age (years)						
30-34	1.0		1.0		1.0	
40-44	4.4	1.8-10.9	4.9	1.8-13.7	4.0	1.6-10.2
50-54	37.8	9.7-147	33.1	8.0-137	27.0	6.9-106
WAI 1996						
Excellent	1.0		1.0		1.0	
Good	3.3	1.3-8.2	3.9	1.4-11.0	2.7	1.0-6.7
Moderate	18.4	5.4-62.2	27.9	7.0-111	13.7	3.7-50.5
Poor	53.3	6.3-452	82.9	6.0->999	30.4	3.5-265

6.5 Reliability of the dynamic stability and functional balance tests (V)

Trial-to-trial reproducibility

The performance time of the dynamic stability test and the functional balance test improved significantly ($p<0.001$) after repeated trials in both test sessions.

After the third trial the improvement between consecutive trials was no longer significant (Fig. 7a-d, Table 2, Study V), and the average difference between the individual means was <0.5 s between the third and fourth trials (Table 3, Study V).

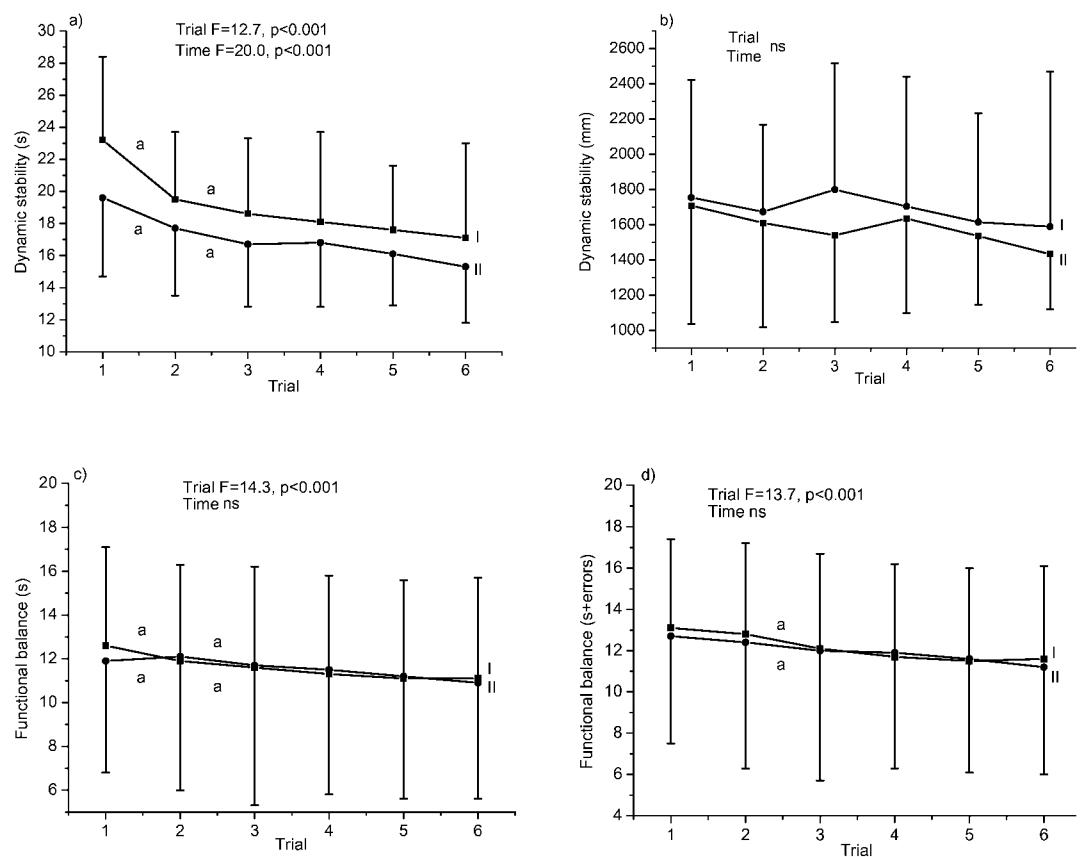


Figure 7a-d. Means and SD of the balance tests measured twice (I-II) with an interval of 2 months and the significant differences between six trials (trial) and between test sessions I and II (time) (n=29), (^a $p<0.05$ for differences between two consecutive trials, ns=not statistically significant).

In both balance tests, the LoA values were larger and the ICC values were smaller almost without exception between the first and second consecutive trials when compared with the results of all the other consecutive trials (Table 12). The differences between the LoA and ICC values of trial combinations 2-3, 3-4, 4-5, 5-6 were minor. The very lowest LoA values, as well as the highest ICC values occurred either between the fifth and sixth (dynamic stability) or the fourth and fifth (functional balance) trials.

Table 12. Limits of agreement (LoA) and the intraclass correlation coefficients (ICC) between the consecutive trials of the balance tests in the first test session (n=29).

Trials	Dynamic stability (s)		Dynamic stability (mm)		Functional balance (s)		Functional balance (s+errors)	
	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC
1-2	3.7 (10.8)	0.16	81.8 (1258)	0.41	0.7 (2.9)	0.84	0.4 (3.7)	0.78
2-3	0.9 (7.8)	0.59	127 (1072)	0.60	0.4 (2.4)	0.90	0.7 (3.2)	0.80
3-4	0.4 (9.2)	0.60	95.1 (1042)	0.73	0.2 (2.1)	0.94	0.4 (2.2)	0.93
4-5	0.6 (10.4)	0.43	88.5 (1135)	0.66	0.2 (1.4)	0.96	0.2 (2.3)	0.93
5-6	0.6 (8.4)	0.64	12.1 (919)	0.81	0.1 (1.7)	0.93	0.0 (2.4)	0.89

Test-retest stability

The performance time of the dynamic stability test in two test sessions with an interval of 2 months was significantly ($p<0.001$) shorter in the retest. The distance was shorter as well, and it was close to statistical significance ($p=0.06$) (Fig. 7a-d).

The LoA and ICC values of the test-retest stability were reported using the best values as the outcome variable because they were smaller than the results obtained in the last trial of each trial combination as a final score. In the dynamic stability test, the LoA values were the smallest (Table 13), and the ICC values were the highest when the test-retest stability was calculated using the best value of five repeated trials as the outcome variable. In the functional balance test the most reliable LoA and ICC values were obtained using the best of three trials as the outcome (Table 13).

Table 13. Limits of agreement (LoA) and the intraclass correlation coefficients (ICC) for the repeated tests (best values of the trial combinations) after an interval of 2 months (n=29).

Best value of trials	Dynamic stability (s)		Dynamic stability (mm)		Functional balance (s)		Functional balance (s+errors)	
	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC	LoA Mean (SD)	ICC
1-2	2.3 (7.8)	0.25	149 (933)	0.54	0.4 (3.1)	0.89	0.6 (3.7)	0.85
1-3	2.0 (6.7)	0.40	173 (687)	0.68	0.2 (2.7)	0.88	0.2 (2.5)	0.90
1-4	1.6 (6.6)	0.56	144 (745)	0.62	0.2 (2.6)	0.92	0.2 (2.7)	0.92
1-5	1.3 (4.2)	0.60	87.4 (572)	0.72	0.3 (2.9)	0.83	0.2 (2.8)	0.86
1-6	1.2 (4.6)	0.50	166 (762)	0.52	0.3 (2.8)	0.88	0.3 (2.5)	0.92
3-6	1.1 (5.0)	0.57	173 (898)	0.72	0.2 (2.8)	0.84	0.2 (2.6)	0.86

7. DISCUSSION

7.1 Main findings

The main findings of this study were that the balance abilities of the firefighters over 49 years of age were poorer than those of the age groups of <40 and 40-49 years. The decline of balance abilities among the construction, home care and nursing workers was not as consistent. Postural balance was also more detrimentally affected among the older firefighters than among the younger ones when they used fire-protective equipment (FPE) without visual input. Self-contained breathing apparatus (SCBA) was the most significant single piece of FPE to impair balance among both the younger and the older firefighters. Furthermore, fast and controlled performance in the dynamic stability test of the firefighters in all the age groups was related to less slip and fall risk with FPE. Older firefighters tended to slip longer and more seriously than the younger ones, but the difference was not significant.

It was also found that the construction workers were faster and made fewer errors than the firefighters in the functional balance test. Among the firefighters, poor performance in the balance tests was shown to be a risk factor for reduced work ability index (WAI) category after a follow-up of 3 years. Finally, the dynamic stability and functional balance tests showed reasonable reliability, especially, when the reliability was estimated from the best of at least three repeated trials.

7.2 Individual-, task- and environment-related aspects of balance control

The results of this study agreed with previous findings of age-related deterioration of postural and functional balance abilities among people of working age (Choy et al 2003, Du Pasquier et al 2003, Gill et al 1991, Pohjonen 2001a, Røgind et al 2003) and of balance being the poorest among people over 50 years of age (Ekdahl et al 1989, Era and Heikkinen 1985). The present results do not agree with those of Hytönen et al (1993) that postural balance was the most stable among healthy volunteers from different occupations aged 46-60 years or with those of Sihvonen et al (1998), who detected only minor decreases in the balance of the working-age population. Although the same measurement tools and parameters would have been used, comparisons of the age-related results reported in different studies are difficult due to differences in the selection of the subjects, the varying age ranges of the subjects, and the differences in study design. As in the previous studies of Colledge et al (1994), Matheson et al (1999) and Straube et al (1988), the age-related differences in the present study among home care and nursing workers were more often significant when the balance task was more challenging (i.e., the BOS was narrow as in

tandem standing and beam walking in the functional test). One reason for the poorer balance among the older subjects in this study, when compared with the results of the younger ones, may be related to their lower muscular capacity. Colledge et al (1994) suggested that the increase in body sway with aging is more likely to be due to the slowing of central integrative processes than to altered peripheral sensibility. Most of the studies of mechanisms contributing age-related balance changes deal with subjects over 60 years of age and young adults (Rankin et al 2000, Teasdale and Simoneau 2001), and they do not include working-age populations.

Furthermore, the present results parallel those of Kincl et al (2002), who showed that the use of FPE also impairs balance performance. Moreover, age and visual condition affected the efficiency of the balance control system to compensate for the inconvenience caused by FPE. In the eyes-closed condition, FPE increased sway clearly more among the older firefighters than among the younger ones. These findings also show that visual afferents are more important in balance control when FPE is used by firefighters over 43 years of age than when it is used by younger ones (33-38 years). The role of vision in balance control has been shown to increase at least after the age of 60 years (Du Pasquier et al 2003, Perrin et al 1997). Recently Choy et al (2003) reported that reliance on vision for postural stability was clear among women aged 40-49 years in a single-limb stance, among 50-to-59 year-olds when they were standing on foam, and among 60-to-69-year-olds on a firm surface. The good balance abilities and physical capacity of younger firefighters, as well as their greater reliance on proprioceptive input rather than visual input in balance control, may help explain their greater ability to compensate for the harmful effects related to the use of FPE in eyes-closed conditions.

In the present study, SCBA was the most significant single piece of equipment to decrease balance performance. According to Egan et al (2001) the United States Army's chemical protective ensemble, which includes a M40 protective mask, a chemical overgarment, gloves, and rubber overboots, but no respirator, does not affect postural balance, even after simulated field tasks of 18 minutes. SCBA affects balance control by shifting the place of body COG, and its weight (15.5 kg) also increases strain on the balance control system. Better balance control in firefighting and rescue operations may be achieved by replacing the currently-used steel air tanks with those made of composite materials, which are at least 6 kg lighter. According to this study, balance performance with the full-face mask of SCBA was also significantly poorer than that in the baseline test. The mask limits visual fields and thus may affect postural control because peripheral vision is important in locomotion and the detection of movement and changes of illumination (Paulus et al 1984, Samo et al 2003, Zelnick et al 1994). This negative effect was not observed in the tests with and without the M40 protective mask (Egan et al 2001). As in the results of

Egan et al (2001) the use of safety boots did not affect the balance of firefighters in this study. Therefore, safety boots do not contribute to a decline in balance performance due to decreased tactile cues from the feet.

SCBA is usually used in difficult, unusual and rapidly changing work conditions, and it is associated with high physical strain. This complex situation offers a greater challenge for a balance control system than basic balance tests in laboratory conditions do. According to Niinimaa and McAvoy (1983) postural sway is greater during the aiming of an air rifle after strenuous physical exercise than it is during the same procedure in rest. An increase in postural sway after a 2-mile run was also reported by Pendergrass et al (2003). It is possible that the negative effect of FPE on balance control in the present study underestimated the effect in actual fire and rescue operations. Some evidence of underestimation has been reported by Kincl et al (2001) and Seliga et al (1991), who showed that postural sway increased more consistently after physical loading with respirators than without such physical loading. These findings may indicate that the use of respirators modifies the ability to maintain balance due to a combination of work-related muscular and general fatigue (Kincl et al 2001, Seliga et al 1991). Fatigue probably detrimentally affects the ability to compensate for the respirator. In conditions of fatigue due to physical exertion, the latency of a response to regulate balance may be increased and may, therefore, have a degrading effect, especially on the emergency reactive control of balance (Hsiao and Simeonov 2001).

The present results showing an age-related decline in balance abilities and negative effects of FPE and eye closure on balance control, as well as the tendency of longer slip distances among older firefighters, are important to consider for safety reasons in actual work situations in physical jobs. Fire and rescue situations usually occur in heavily smoky or totally dark environments in which visual feedback is poor, although not absent as in the eyes-closed condition. In alarm situations, several complicated aspects of work and the environment have to be taken into account. Complex tasks that divide a worker's full attention can reduce his or her ability to execute proactive control of balance (Hsiao and Simeonov 2001). Especially among older subjects, less attentional processing capacity is available for balance control during a dual-task paradigm (Rankin et al 2000). For example, balance control has been shown to be poorer when subjects perform a simultaneous cognitive task than when balance performance takes place alone (Shumway-Cook et al 1997, Shumway-Cook and Woollacott 2000). Furthermore, Hsiao and Simeonov (2001) and Parnianpour et al (1989) have suggested that the decline in postural control due to age or inexperience may contribute to accidental falls at work. It can be hypothesized, however, that experienced older workers may be able to use their professional competence and efficient work techniques to compensate for their age-related decrease in balance control, for example, the disadvantage related to

the use of FPE. This possibility is important because the mean age of Finnish firefighters is 39 years (Tilastokeskus 2003), and it will increase in the future because firefighters' retirement age has been raised from 55 to 65 years. According to Lusa et al (1994) every firefighter has to carry out tasks with FPE at least a few times a year regardless of age. Although work in the fire and rescue service has changed and diversified much during the past few decades, it will contain the regular use of FPE.

Occupation-related differences in balance

In this study balance abilities were better for the workers whose work also demanded high balance control. Compared with the construction workers, the firefighters performed more slowly and also made more errors in the functional balance test. Firefighters operate on roofs or use ladders, on the average, once in 3 months, depending on the number of alarms (Lusa et al 1994), whereas construction workers almost daily climb and work for many hours on high scaffoldings. In general, the home care and nursing staff performed more poorly than the firefighters and construction workers did in the functional balance test, and more poorly than the firefighters in the postural balance test in a normal standing position. On the other hand, the home care workers were superior in the tandem standing position. The demands of the functional balance test may be closer to those of dynamic physical jobs, and the differences between the occupational groups were more consistent in the functional balance test than in the postural balance test. Moreover, the average results of postural balance in this study did not differ from the reference values of the force platform system that was used (Metitur 2001).

The work environment may positively influence balance abilities by providing the opportunity for intensive and specific training and the learning of balance skills. According to Pajala et al (2004), individual environmental factors accounted for up to half of the variance in postural balance among older women. For example, fighter pilots had better balance control than candidates for flight training (Kohen-Ratz 1994), and construction workers showed lower body sway than workers not engaged in manual work (Gantchev and Dunev 1978). Unfortunately the present study did not collect postural balance data for the included construction workers. Diard et al (1997) suggested that the better performance of fighter pilots on active duty in comparison with that of retired pilots is an acquired skill, that requires continuous training. In addition to learning and training in respect to environment- and task-related balance demands of work, differences in balance abilities between occupations may be explained by genetic effects (Kohen-Ratz et al 1994, Pajala et al 2004), as well as by worker selection to a specific job. Genetic effects accounted for one-third

of the variance of the balance factor, which consisted of data from postural sway measurements in normal and semi-tandem positions (Pajala et al 2004).

The aforementioned findings of occupation-related differences in balance between male- and female-specific occupations are preliminary, and they need further clarification because of the possible differences between the sexes. Some studies have shown balance differences between men and women, but the findings are conflicting or the standardization of anthropometrics removed the difference (Era et al 1996, Juntunen et al 1987, Maki et al 1990, Matheson et al 1999, Panzer et al 1995). The differences in functional and postural balance between home care and nursing staff in the present study cannot be explained by different balance demands of the work. In the tandem standing test, the difference between home care and nursing staff disappeared when muscle strength and endurance of the legs were used as covariates, but it remained significant in the functional balance test. In this study no results were available on the maximal rate of force development, which may be a more important factor in balance control than maximal strength (Izquierdo et al 1999) or muscle endurance. Among people aged 40 and 70 years, a decreased ability to develop force rapidly seems to be associated with a lower capacity for neuromuscular response in controlling postural sway (Izquierdo et al 1999).

7.3 Slip and fall risk in association with age, balance and muscular capacity

Although the younger and older firefighters experienced as many slips in walking trials, there was a trend towards higher age negatively affecting slip distances and the seriousness of the slips, especially in the tests with a faster walking speed. The age range of the older firefighters was also larger (33-38 and 43-56 years) and therefore produced a high standard deviation and reduced the differences between the age groups. Slip distances of 2-50 cm were detected. Most of the slips were, however, well controlled, even if their length was about 20 cm, and, in some cases, balance could be regained without the safety harness. The recommended maximum tolerable criterion for a slip distance ranges from 5 to 22 cm (Brady et al 2000, Grönqvist et al 1999, Strandberg and Lanshammar 1981). According to Leamon and Li (1991), an additional load increases slip distance as well. Therefore, the use of FPE may have produced long slip distances in the present study. Furthermore, the muscular endurance of the lower extremities of the firefighters in the present study could be classified as at least good (Lusa 1994). It is possible that the good muscular capacity of the firefighters allowed long controlled slips. Postural activity from bilateral leg and thigh muscles and coordination between the two lower extremities have also been shown to be key factors in reactive balance control in slips occurring at heel strike (Tang et al 1998).

The firefighters whose sliding distance with glycerol was critical (i.e., ≥ 5 cm) tended to have poorer results in the balance and muscular capacity tests than those who slipped less than 5 cm at a walking speed of 100 steps/min. The difference was significant only for the dynamic stability test. The same tendency was seen with the speed of 120 steps/min, but no differences were significant due to the smaller number of studied firefighters (because of technical reasons four firefighters' results were not available).

The dynamic stability test is based on visual feedback on the movement of the COP through the targets shown a computer screen. Therefore, the efficient utilization of visual input in balance control may be an important protective factor with respect to slip and fall risk. Although the balance task is to move the COP actively in the dynamic stability test, it cannot go over the BOS in a successful test. For a forward slip during walking, a smaller movement and faster velocity of the body's COM over the BOS plays a significant role in slip recovery and fall termination from heel strike to contralateral toe off (You et al 2001). Furthermore, the dynamic stability test primarily demands the use of ankle strategy, which is one of the protective responses after the onset of a slip as well. The ankle moment has been shown to decrease with the severity of the slip, and knee flexor and hip extensor moments have been found to be primarily responsible for corrective balance reactions (Cham and Redfern 2001). Therefore, in actual work situations, ankle strategy may be insufficient to prevent falling during a slip event.

7.4 Predictive value of balance for work ability and the reliability of the dynamic balance tests

Poor perceived balance abilities, many errors in the functional balance test, and a high amplitude of postural sway with the eyes closed were the most significant predictors of decreased WAI after the 3 years of follow-up in this study. The errors in the functional balance test showed almost 4-fold risk for decreased WAI when compared with an accurate performance in the test. At baseline, good performance time in the functional balance test was also associated with good WAI and PWA. Performance time in the functional balance test has been shown to be a strong predictor for WAI among home care workers (Pohjonen 2001a) as well. In difficult environments of actual fire and rescue work, both accurate and rapid balance adjustments are challenged and needed. Findings of occupation-related differences in this study also suggested that performance in the functional balance test may be related to the balance demands of physical work. According to the results difficulties to control balance without visual input in the postural balance test may also reflect problems with work ability.

The question of perceived balance may include specific aspects of balance needed in fire and rescue work. It can be hypothesized that the studied firefighters considered extrinsic factors, such as difficult work environments and challenging work tasks, when they evaluated their ability to balance in respect to the demands of fire and rescue work. Furthermore, like perceived balance, both WAI and PWA are based on subjective opinion, which probably also affected the close association between perceived balance abilities and WAI and between perceived balance abilities and PWA. Previously, Chiou et al (1998) showed promising results for the Perceived Sense of Postural Sway and Instability Scale among industrial workers in evaluating the possible loss of balance at work. The ability to perceive balance demands correctly was critical if the necessary postural stabilization processes were to be triggered during work. It was concluded that workers were able to perceive their postural sway due to changes in peripheral vision, environmental lighting, workload and surface firmness. In the present study the used perceived balance abilities and the functional balance test are simple, easy and unequivocal to perform and interpret in occupational health services. The method using a force platform for measuring postural sway is more complicated, but it offers a reliable means of studying the basic balance function with different sensory conditions.

Furthermore, six repeated trials showed improving results in both of the dynamic balance tests. This learning effect may be related to a person's ability to change postural strategy to a more efficient one (Hertel et al 2000, Hirvonen et al 2002). According to Hansen et al (2000) the learning process is more pronounced for dynamic balance tests than for static ones. In the present study, a baseline level was attained for performance time in the dynamic stability and functional balance tests after three repeated trials. The results supported the concept of using more than one trial to obtain reliable balance results (Hertel et al 2000, Hirvonen et al 2002). The performance time in the dynamic stability test of the present study was also shorter in the test-retests done after an interval of 2 months, whereas there was no significant difference for the functional balance test. The major learning effects associated with the dynamic stability test, when compared with those of the functional balance test, can partly be explained by the different balance tasks evaluated. Walking belongs to habitual activities of daily living, which alleviates the learning effect, whereas the firefighters moved their COP through the targets on the computer monitor for the first time. Kinzey and Armstrong (1998) hypothesized that reliable balance tests should possibly involve tasks that simulate daily activities.

Almost all of the ICC and best LoA values of the repeated trials in the functional balance test showed good trial-to-trial reproducibility. Although most of the ICC values of the dynamic stability test were moderate between six repeated trials, the LoA values between repeated trials were broad and indicated low absolute trial-to-trial consistency and wide individual variation. Large

individual variation was also previously reported to be a typical problem in the evaluation of balance control within a normal population (Birmingham 2000, Hansen et al 2000, Takala et al 1997). Large variation may hamper, for example, a reliable evaluation of the changes in balance control. In general, the individual variation in the balance results of the present study was high. That observation and previous results strengthen the need to use the best or average value for repeated trials as an outcome variable for reliability, as shown previously to improve the reliability of balance tests (Corriveau et al 2000, Mustalampi et al 2003). In addition, the sample size was small, and large changes in the results of one studied individual made the LoA values significantly broader. The sample size of previous reliability studies of dynamic balance tests range from 16 to 57 (Brouwer et al 1998, Hertel et al 2000, Hirvonen et al 2002, Punakallio et al 1997a, Rätty et al 2002, Rinne et al 2001), and some reliability studies of postural balance have been carried out with less than 10 subjects (Corriveau et al 2000, Takala et al 1997).

In the present study, the highest test-retest reliability (moderate level, $\text{LoA} \pm 4$ s and ± 572 mm) was attained in the dynamic stability test when the best results of the five first consecutive trials were used as the outcome variables. With the exception of the first trial combination (best of trials 1 and 2) as an outcome variable for the functional balance test, the reliability of different trial combinations was very similar and showed good stability. LoA values of ± 2.5 s (best of three trials) were also reasonable. The ICC values of the functional balance test were at the same level as previously reported for functional tests (Hertel et al 2000, Rätty et al 2002, Rinne et al 2001) and lower for the dynamic stability test when compared with the findings of previous studies (Brouwer et al 1998, Hirvonen et al 2002). The tasks in the dynamic stability tests differed, and, therefore, the reliability of these tests is specific for each method.

7.5 Methodology

7.5.1 Subjects

The present data were based on a stratified sample, and not only healthy volunteers were invited to participate. Therefore, the dropout rate of 27% during the 3-year follow-up is reasonable and describes a normal phenomenon in worklife. The reasons for the dropout were also obvious. For example, over half of the dropouts retired on an old-age or disability pension or were on long-lasting sick leaves, and 15 subjects were unwilling to participate in the follow-up tests for personal reasons. Generalization of the results to the entire study group is supported in that the balance test results, the WAI and the PWA did not differ significantly at the baseline between the study sample and the dropouts in

Study IV. Furthermore, the characteristics of the southern Finland firefighters in Study I did not differ with respect to the entire sample measured in 1999.

Although, the studied firefighters in Studies II, III and V were volunteers, and six of them were excluded from the study because of their musculoskeletal disorders, their results at baseline were similar with respect to balance, muscle and cardiorespiratory endurance and the frequency of physical exercise of the entire sample of firefighters at baseline and also when compared with the sample of firefighters from southern Finland in 1999. The mean age of the firefighters (41-42 years) in Studies I-V was at the same level as the mean age of all professional firefighters in Finland (i.e., 39 years) (Tilastokeskus 2003). All the studied firefighters were men since, at the time, there was only one female professional firefighter in Finland.

In addition to firefighters, Study I included construction workers, home care workers and nursing staff. These subjects represented ordinary workers of different ages in four occupational groups without any specific background of motor skill training. The subjects were either randomly chosen or all the workers from certain work units were selected for the study, and not only volunteers were invited. In some cases, the group sizes were small, in most cases below 25 and in four cases below 15. Although the studied occupational groups were small, the participation rates of the eligible subjects were high (84-88%).

7.5.2 Methods and study design

Balance measurements

Two physiotherapists performed the balance measurements in Study IV and those on firefighters and home care workers in Study I. Two different physiotherapists tested the nursing staff and construction workers. In Studies II, III and V the same physiotherapist conducted the measurements and, in study V, also on both occasions. All the physiotherapists were well-trained and experienced professionals. In addition, the reliability between two well-trained physiotherapists was shown to be high with respect to the functional balance test ($r=0.95$, $p<0.001$, $n=12$) (Punakallio, unpublished data). The present dynamic stability and functional balance tests have previously shown some learning effects between repeated trials, and their reliability was not defined according to current recommendations in exercise sciences (Atkinson and Nevill 1998, Hoffman 1998, Punakallio et al 1997a). Therefore the test-retest reliability of these two dynamic balance tests was investigated in Study V (See section 7.4).

In the functional balance test, in addition to short performance time, no or few errors can be considered to show good control of performance. When a sum variable (performance time + number of errors) was used, a time measurement of 1 s was chosen as one error. Then the proportion of errors (range 0-6 for the

subjects in this study) increased the mean performance time (range 10-23 s) of the sum score, but the errors were not emphasized in the sum score.

The postural balance tests performed in this study are widely used, and the reliability of the used parameters was acceptable (Mustalampi et al 2003, Takala et al. 1997). The reliability of perceived balance abilities needs to be established.

In Study II, of balance abilities and FPE, the firefighters first performed the baseline postural balance tests in two visual conditions and the baseline functional balance test. Thereafter, two postural balance tests and four functional balance tests were performed with different equipment combinations. Furthermore, in Study V, on trial-to-trial reproducibility, the balance tests were repeated six times. The firefighters included in both studies were highly motivated to perform all the repeated tests well. The tests were brief and physically undemanding, and fatigue hardly affected performance. If there was a learning effect from the four and five repeated trials in Study II, it would probably have only reduced the differences between the baseline balance tests and the tests with FPE.

Slipping tests

So that the unexpected and surprising nature of slipping in the tests would be preserved, the number of trials were limited as much as possible. The firefighters received no information on the number of trials they would perform or on the slipperiness and slip-resistance of the path. Anticipation of slipping could not completely be avoided, and it may have affected the slipping responses and, therefore, possibly diminished the differences between the firefighters. Previously, it has been shown that a more cautious walking strategy seems to be adopted when a potential slip risk exists (Cham and Redfern 2002, Marigold and Patla 2002). Because of the anticipation and test method, the present slipping responses obtained in the laboratory may also differ from those in actual firefighting situations, which often include disturbing factors such as noise, poor lighting and psychological stress. A track with curves, uphill, and downhill, and different kinds of obstacles would be closer to actual work situations than the straight path used in Study II. In addition only one foot stepped on the slippery surface. A larger slippery area would be nearer actual environmental conditions.

Work ability index

Because the concepts of job performance, work capacity and work ability are rather confusing and therefore difficult to define, their operationalization is also problematic, and there is a lack of valid measures for them (Pohjonen 2001b). Using the stress-strain concept (Rutenfrantz 1981, Ilmarinen et al (1991) have

defined work ability as a worker's capability to manage his or her job demands. This group of Finnish researchers also constructed a questionnaire-based measure, the work ability index (WAI) (Tuomi et al 1991, Tuomi et al 1998), to operationalize the concept of work ability. The mean WAI score and its classification into WAI categories have been reported to be stable over a 4-week interval at the group level. Repeated assessments of WAI have also provided evidence of acceptable test-retest reliability at the individual level (De Zwart 2002). In addition, the WAI is a sum variable, which also includes many other aspects of work ability than physical work capacity.

In cross-sectional studies, prerequisites of work ability for physical jobs (i.e., good performance in motor, musculoskeletal and cardiorespiratory capacity tests) are associated with a good WAI among firefighters (Pokorski et al 2004, Punakallio et al 1997b). Good performance on physical capacity tests (balance, muscle strength) was strongly associated with the physical demands and WAI of home care workers as well (Pohjonen 2001). Among firefighters, the higher categories of the WAI were also significantly associated with quicker performance through a labyrinth in a smoke chamber (Pokorski et al 2004).

8. CONCLUSIONS AND RECOMMENDATIONS

This study was carried out among workers in physically demanding occupations, mainly among firefighters. The demands for balance control have been characterized as high in fire and rescue tasks. Based on the results of this study, the following conclusions and recommendations are justified:

1. Balance abilities of firefighters aged 50 years and over are poorer than those of younger firefighters. The differences in balance abilities are not as consistent among different aged construction, home care and nursing workers. Furthermore, postural balance is more harmfully affected among older firefighters than among younger ones when they use FPE with their eyes closed. SCBA proved to be the most significant single piece of equipment to decrease balance performance.

These aspects should be taken into consideration during the organization of work tasks in fire departments and in the development of the characteristics of FPE. It is also essential to provide ample balance training opportunities for firefighters with and without FPE. These findings also support the need for including balance assessments when the prerequisites of work ability are evaluated for firefighters.

2. The ability to exploit visual feedback efficiently in balance control seems to be associated with smaller slip risk, whereas associations between muscular capacity and the risk of slipping are not significant. Older firefighters also tend to slip longer and more seriously than younger ones.

In respect to safety aspects on slippery surfaces, methods based on visual feedback may provide useful information of balance control, and, therefore, this kind of test may be useful in evaluations of balance ability among workers in physically demanding jobs.

3. Many errors in the functional balance test, a high mean sway amplitude with the eyes closed, and a poor estimate of one's own balance abilities predicted reduced WAI category after the follow-up.

Balance abilities proved to be related to perceived work ability, and the aforementioned tests and parameters may therefore be useful when prerequisites of work ability are evaluated for firefighters.

4. The functional balance test showed high trial-to-trial reproducibility and stability over time, and for the dynamic stability test the result was moderate.

The narrowest limits of agreement, about ± 2 s in the functional balance test and about ± 4 s in the dynamic stability test, would be acceptable for practical use as well.

To improve the reliability of functional balance and dynamic stability tests, three and five trials, respectively, should be carried out after one pretest. Then the best trial value should be used as the final result.

5. On the whole, in respect to safety and work ability in fire and rescue work, the present results suggest that, when the work ability of firefighters is being followed-up the balance abilities should be taken into account. The balance assessments of the present study can be included when prerequisites of work ability are evaluated for firefighters. The approach of the present study, in which balance control is considered an interaction between a worker's individual characteristic and the demands of daily work tasks and the work environment, appeared to be relevant when the balance abilities of workers in physically demanding jobs were studied. It may be useful to adapt the frame of reference of the present study for studies on workers from other physically demanding occupations as well. Additional investigations of balance abilities utilizing the frame of reference of the present study can be recommended. These studies should include versatile individual-, task- and environment-related parameters in association with balance.

It would also be useful to study the occupation- and age-related differences in balance and the associations between slip risk, age and balance with studies of larger numbers of subjects in various physical jobs. Methods are needed for studying balance demands of actual or simulated work tasks, and valid field and laboratory balance tests based on the actual work balance demands should be developed for workers from different kinds of physical jobs. In the laboratory balance abilities and the risk of slipping and falling during walking should be tested concurrently to provide more understanding of individual balance abilities in respect to slip-related accidents and to provide a validation of balance tests in respect to slip and fall risk. The effect of fatigue as well as exercise on slip and fall risk and balance control on slippery or other difficult surfaces and the environment should also be studied.

YHTEENVETO

Työskentely katoilla, savusukellus, pelastettavien ja raskaiden työvälineiden nostaminen ja kantaminen ovat esimerkkejä tyypillisistä tehtävistä palo- ja pelastustyössä, joissa hyvä tasapainokyky on erityisen tärkeää turvallisuuden ja sujuvan työsuorituksen kannalta. Lisäksi hankalat ja nopeasti vaihtuvat työolosuhteet sekä savusukellusvarustuksen käyttö lisäävät haastetta kehon asennonsäätelyjärjestelmälle. Riittävän hyvä tasapaino on yksi oleellinen fyysisen työkyvyn edellytys myös muissa fyysisesti raskaissa ammateissa, joihin kuuluu painavien esineiden käsittelyä ja liikkumista monimutkaisissa olosuhteissa.

Työntekijät ikääntyvät ja myös tasapaino heikkenee iän myötä. Fyysisesti kuormittavien töiden tasapainovaatimukset ovat kuitenkin samanlaiset ikääntyvillä ja nuorilla työntekijöillä. Huomattava osuus, esimerkiksi 30% palomiesten, 22% rakennusmiesten ja 25% hoito- ja sosiaalialalla työskentelevien työtapaturmista on liukastumisten, kompastumisten ja kaatumisten aiheuttamia. On myös viitteitä siitä, että liukastumiseen liittyviä tapaturmia tapahtuu enemmän yli 45-vuotiaille työntekijöille. Aikaisemmin ei ole juurikaan tutkittu fyysisesti kuormittavaa työtä tekevien työntekijöiden tasapainoa yhteydessä työkykyyn ja työturvallisuuteen.

Tämän tutkimuksen tarkoituksena oli selvittää tasapainokyvyn ja iän, ammatin sekä savusukellusvarustuksen käytön välisiä yhteyksiä sekä liukastumisriskin ja tasapainokyvyn välisiä yhteyksiä fyysisesti kuormittavissa ammateissa toimivilla työntekijöillä ja erityisesti palomiehillä. Lisäksi tavoitteena oli tutkia ennustaako tasapaino muutosta koetussa työkyvyssä ja selvittää kahden dynaamisen tasapainotestin toistettavuus.

Tutkimus sisältää viisi tutkimusta, joihin osallistui 29-135 vakinaista 30-56-vuotiaasta palomiestä. Iän, ammatin ja tasapainon välisiä yhteyksiä selvittäneeseen poikkileikkaustutkimukseen osallistui palomiesten lisäksi 23-61-vuotiaita rakennustyöntekijöitä sekä kotipalvelu- ja hoitotyöntekijöitä. Seisomatasapaino (kehon huojunta) mitattiin voimalevyllä normaalissa ja tandem seisoma-asennossa tutkittavan silmät auki ja kiinni. Lisäksi voimalevyä hyödynnettiin näköpalautteeseen perustuvassa dynaamisessa testissä, jossa tutkittavan oli kehon painopistettä liikuttamalla kuljetettava kursoria tietokoneen näytön osoittaman ympyrän kehällä. Toiminnallinen dynaaminen tasapaino mitattiin testillä, jossa tutkittava käveli etu- ja takaperin puisella puomilla sekä koettua tasapainonhallintakykyä arvioitiin kyselylomakkeen avulla. Yhdessä tutkimuksessa tasapainotestit suoritettiin sekä savusukellusvarustuksessa että ilman varustusta. Lisäksi tutkittavat kävelivät savusukellusvarustuksessa 8 m pitkällä suoralla radalla, josta yhdelle alueelle oli levitetty vettä ja pesuainetta tai glyserolia. Mahdollisten liukastumisten pituus kävelysuunnassa mitattiin. Koettu työkyky mitattiin työkykyindeksillä lähtötilanteessa sekä kolmen vuoden

seurannan jälkeen. Reliabiliteettitutkimuksessa dynaamisen tasapainon testit toistettiin kuusi kertaa peräkkäin kahdella mittauskerralla, joiden väli oli 2kk.

Tulokset osoittivat, että yli 49-vuotiaiden palomiesten kehon tasapainonhallinta oli merkitsevästi heikompia kuin 40-49 ja alle 40-vuotiaiden palomiesten tasapaino. Ikäryhmittäiset erot tasapainossa eivät olleet yhtä selkeitä rakennusmiehillä, kotipalveluhenkilöstöllä ja hoitohenkilökunnalla. Vanhemmat palomiehet (43-56-vuotta) huokuivat merkitsevästi nuorempia (33-38-vuotta) palomiehiä enemmän seisomatasapainotestissä silmät kiinni savusukellusvarustus yllä verrattuna vastaavaan tulokseen urheiluvarustuksessa. Paineilmalaite osoittautui merkitsevimmäksi yksittäiseksi palonsuojavarusteeksi, joka heikensi tasapainonhallintaa molemmissa ikäryhmissä. Edelleen, molemmissa ikäryhmissä nopea ja tarkka suoritus näköpalautteeseen perustuvassa dynaamisessa testissä oli yhteydessä pienempään riskiin liukastua ja kaatua. Vanhemmat palomiehet liukastuivat pidemmän matkaa verrattuna nuoriin palomiehiin ja joutuivat ponnistelemaan enemmän säilyttääkseen tasapainonsa. Rakennusmiehet olivat palomiehiä merkitsevästi nopeampia ja tekivät vähemmän virheitä toiminnallisessa tasapainotestissä. Lisäksi heikko suoritus tasapainotesteissä ennusti merkitsevästi myös työkykyindeksin heikkenemistä kolmen vuoden seurannan jälkeen. Näköpalautteeseen perustuvan dynaamisen testin ja toiminnallisen tasapainotestin toistettavuus voitiin luokitella kohtuulliseksi ja hyväksi, erityisesti kun tehtiin vähintään kolme suoritusta, joista paras valittiin tulokseksi.

Tulosten perusteella voidaan suositella, että tasapainokyky tulisi ottaa huomioon palomiesten työkyvyn seurannassa, työjärjestelyissä sekä savusukellusvarustuksen ominaisuuksien kehittämisessä. Tässä tutkimuksessa käytettyjä tasapainon mittausmenetelmiä voidaan käyttää osana palomiesten työkyvyn fyysisten edellytysten seurantaan. On myös tärkeää tarjota riittävästi mahdollisuuksia tasapainoharjoitteluun palonsuojavarustuksen kanssa ja ilman sitä. Tässä tutkimuksessa käytetty viitekehys, jossa tasapaino nähdään yksilön, työtehtävän ja ympäristön välisenä vuorovaikutuksena, vaikuttaa relevantilta fyysisesti kuormittavaa työtä tekevien työntekijöiden tasapainon tutkimisessa ja viitekehystä voidaan suositella sovellettavan myös muissa fyysisesti kuormittavissa ammateissa. Tarvitaan myös menetelmiä arvioimaan aitojen tai simuloitujen työtehtävien tasapainovaatimuksia ja työn tasapainovaatimuksiin perustuvia testejä tulisi kehittää fyysisesti kuormittavaa työtä tekeville työntekijöille. Pitäisi myös selvittää väsymyksen ja fyysisen harjoittelun vaikutukset liukastumis- ja kaatumisriskiin sekä tasapainonhallintaan liukkaalla tai muutoin vaativalla alustalla ja vaihtelevassa ympäristössä.

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